COLOR in Black and White
An Investigation of Vividness in Color and in Architecture

by

John Martz Rees, B.A.

Thesis

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SUPERVISING COMMITTEE:

Michael Benedikt

Bob Mugeraurer

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ABSTRACT

COLOR in Black and White:
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John Martz Rees, M.S.A.S.
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SUPERVISOR: Michael Benedikt

The exposition of Color in Black and White reconstructs what Aristotle, Leon Battista Alberti, Sir Isaac Newton and Hermann von Helmholtz contributed to the abstraction of sight and to the interaction of color and language. I argue that sensing is as guided by perception as it is by the objects sensed. I attempt to show that linguistic facility and visual experience interpenetrate to such a degree that what we can see is restricted by what we might say and the inverse, that what we say is circumscribed in what we see. The second half of the thesis turns from the general consideration of abstract color concepts to a consideration of two color reproductions; one a painting by Claude Monet, Grainstacks (End of Summer, 1890-1891), and an ekphrasis, Sunflower at Sunset Yellow. I use Grainstacks to develop a seven layer schema for discussing vivid color. I test the schema by offering a plausible description of a color impression: sunset in a western Kansas landscape and an architectural impression: Balthasar Neumann's Church of the Holy Cross at Neresheim (1749). The conclusion comments on the relationship between the perception of color and the perception of space in painting and in architecture.

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Chapter One of COLOR in Black and White

Sunflower at Sunset Yellow

In 1992 I looked so that what I saw was color. This essay is my description of the way I looked, what I saw and how it effects what I design. It begins with a story.

> I drive a lot. I like long distance driving. Strange and wonderful things happen on the road to those who pay attention and can spare the time. I have the time because I traded a regular schedule and a regular income for the luxury of time; time to read, time to think, and time to contemplate (my irregular income).
>
> It's late August and I am driving Fort Collins to Austin through Kansas City. I often travel "blue highways" for fun but on this particular trip I am forced to take the back roads. I have a bed rolled up on the top of the car and the conventional route; south on Interstate 25 to 70 east, is wet, very wet. I see the storm clouds down there and I see the rain coming in sheets. It is 3 o'clock in the afternoon and just outside of Fort Collins it is sprinkling while the sun shines.
>
> Heading due east out of town I am playing tag with light rain all the way to Fort Morgan. Clearing the Colorado border it is not raining but I am trapped in a tangle of county roads that dip in and out of Kansas and Nebraska with no direct route east. I am four hours into an eighteen hour trip that is starting to look like an ordeal. I am beginning to think about making tracks, after all there is not much to see driving alone at night. I pick a route headed generally south, looking for a highway heading east. "Sunflower State Highway 27", crooked and in need of repair, turns out to be a good choice.
>
> As twenty-seven wanders this way and that, through dry land farms and around hills, the sky is successively in different aspect, in view. It is a classic western sunset, blood orange orange sun, a band of clouds, a humbling horizontal expanse. The sun, not perfectly round, is partially obscured. The cloud bank is an absolutely hueless gray with a motley fringe decomposing

towards the zenith into a wispy, lilac rose. Sky colors grade from azure, to indigo, to smalt, to cerulean, at the horizon opposite. The accident of a winding road allows me to view these aerial conditions in some isolation. I am driving inattentively, gazing towards the far distance, observing the sky, when a spark, an explosion really, captures my attention--ALL OF IT. I am rudely interrupted when my focus is redirected by a blink reflex in which attention gets reconstituted as acquisition. DANGER!

But, I am not in danger. In an instant I know the interruption to be a mirroring of the sun from a marker down the road. I am squeamish from the shock of being ripped out of my sky-color reverie, but this new experience suggests another line of introspection. I turn my question towards the sign, now tinged with the scattered rays of the setting sun. What color was it? I remember a self luminous orange, literally day-glo; but now the sign color looks fake, an OSHA orange, compared to the vividness of the vegetation.

I ask myself, for the thousandth time, "Why is green so green at the gloaming?" Rapt in a fresh reverie (this is why I like to drive cross-country) I pass the no passing zone, crest a hill, and drop down into a valley ablaze in sunflowers. The scene is dazzling but not so rude an interruption as was the sign, in this case coaxing my attention, willingly granted.

The valley is a shallow bowl about one-and-a-half miles across. The horizon is high and close. The road bisects the valley into a fallow field on the south and the field of sunflowers on the north-west. The heads of the sunflowers are facing away from the sun and slightly skywards. The sky in sunset is spread wide across my whole visual field. The yellow of the sunflowers seems every bit as intense as the orange of the setting sun, I pull over to the side of the road at about the middle of the valley.

The highway is deserted. As I get out of the car I hear the sound of an invisible jet high overhead. I stretch my legs and scan the horizon. Facing away from the sun the landscape is dark and green; but what color green? I remember it (remembering color memory often plays tricks) as...

apple-green, willow-green,
swallow-gray, sauce brown,
sky-blue, peach-pink, jade,
lotus stem, silver green,
fish-belly-white, ink wash,
pebble-blue, reed-flower,
litche, coral color,
duck's-head green.

But, I stopped to observe the sunflowers so I turn around, vision refreshed, to look again at the sun, sunset, and flowers. The yellow petals are vivid, but now the seed portion of the flower is insistent. It is brown, velvety, deep in hue and highly saturated. Looking again, closer; the seeds are softly brown, rust-brown, ochre-brown, and walnut-brown in a variegated dark chocolate with a yellow halo. It is a totally different color, related to "linguistic" brown but richer, thicker.

I am close upon the field juxtaposing sunflower petal and back-lit sky. I blur my vision to obliterate the details. I am looking *and* unfocused for what seems like several seconds. When I look again I recognize that for a brief moment, just prior to seeing, I did not perceive anything, not sunflowers, not light, not black, nothing. Attentive again, I compare a yellow petal to the setting sun. The sun easily overwhelms the petal color which is not so much less saturated as it is lighter without being whiter. I walk back to the car and write these notes. At the onset of astronomical night first the seeds of the flowers go; the petals dim and briefly, glow. Black goes the sky. Where is no moon?

Suddenly I realize what I thought was the sound of a jet is the sound of wind, blowing high across the high plains. The bugs are out and I am off...goin' to Kansas City, Kansas City here I come.

Chapter Two of COLOR in Black and White

INTRODUCTION

Art historians and other academic culture critics, assessing the reproductions from which art is taught and studied, generally prefer black and white pictures of paintings.

> Since the ordinary photographic plate is sensitive to a larger range of shades than can be recorded in colour, the best black-and-white reproduction...is comparable to a conscientious piano transcription of an orchestral score, whereas the colour print, with some exceptions, is like a reduced orchestra with all the instruments out of tune. Colour photographs and colour prints have indeed fostered a coarseness of vision in art that is likely to be increased by colour television.

The assessment, from Edgar Wind's *Art and Anarchy* (1964:165-6), is typical in the literature even as it draws a particularly good analogy between color perception and acoustic transcription. Obviously the marketplace does not share the opinion of academics since color television is a mainstay of advertising, but I think Wind's opinion has much to recommend it. Every mechanical reproduction of an otherwise singular object involves the elimination of some aspects and the transformation of other aspects crucial to the object's effect. A mechanical reproduction that calls attention to itself as a reproduction by obviously omitting some attributes while effectively conveying others, is a more acceptable substitute than a reproduction that gets everything subtly wrong. Be this as it may, historians on the history of reproduction are often anachronistic and humorous; knocking color reproduction just as commerce rushes to perfect it. There is

no perfecting it, of course, and I side with those who make of vice a virtue, in black and white.

Without the humor this thesis, "Color in black and white," is a conundrum: "properly a riddle depending upon a play upon words, often a puzzle which is scarcely worth the guessing."[1] The conundrum within this thesis is a variation of the youth's riddle "What is black and white and read all over?" The answer 'scarcely worth guessing' is "Color in Black and White" and the pun "read" for "red" hints at a "fantastic resemblance between things quite unlike:" pigments and words, experiences and descriptions, the sensation of color and the reading of words. It is quite odd and rather pretentious to think that one can write [say] something worth reading [saying] about color as experience. From this point of view the visual response to a particular distribution of energy is  [read: an experience] and language just gets in the way. As Paul Valery observed: "to see is to forget the name of the thing one sees" (in Weschler, 1982:203).

I have some sympathy for Valery's point of view and will argue below that the concept "primary color" is a linguistic construct and a scientific "fact" that oversimplifies the study of color. "Color in Black and White" however, is *not* about the study of color for the sake of color science. It is about the play of ideas, the cultural knowledge in color and in stories told about color by scientists, artists and other philosophers. In the end I aim to describe the phenomena of vividness in color and speculate on vividness in architecture. In the mean time "Color in Black and White" acknowledges the conundrum "reading

red" with an assumption.

I assume the validity of a realist point of view. "Realism may be briefly defined as the doctrine that *things exist independently of our knowledge of them*" writes Henry Evelyn Bliss in his pithy gloss of realism. He goes on to say:

> This doctrine maintains that objects are external to subjects and that concepts are *not* independent of objects; that *external* means outside of in a physical sense; that what enters the mind, or the brain, is not the object *per se* but either some sense-impression produced by some physical action transmitted from the object, or else some idea, somehow derived from an external object or subject; that these external objects are existent things and are realized in properties, qualities, actions, and relations that are inherent in them and constitutive of them; that these entities, though imperfectly known, are progressively discovered; that their real existence, or reality, is thus antecedent to the knowledge, or realization, of them by individual minds; [and] that each subjective mind is dependent on an individual objective human body...[2] (1929:171, emphasis in original)

I adopt a realist position because I think that is how the world occurs for artists, scientists and other persons not previously committed to an epistemological position.

Assuming a realist point of view does not however, entail assuming a foundationalist one. I think that just because there is something called reality, to assume something called "Truth" necessarily follows, assumes too much. I am a pragmatist. I agree with Richard Rorty (b.1931) that Truth with a capital "T" does as much to get in the way of inquiry as it does to clarify the nature of objects. In "Pragmatism, relativism, and irrationalism" (1979) Rorty defines pragmatism as

> the doctrine that there are no constraints on inquiry save conversational ones--no wholesale constraints derived from the nature of the objects, or of the mind, or of language, but only those retail constraints provided by the remarks of our fellow inquirers. (1982:165)

I have been warned of the dangers inherent in this slippery slide into radical relativism yet the combination of believing that truth is a fiction and acting as if the fiction is real, makes for the most thrilling life.

I also agree with Paul Feyerabend (1924-1994) "that the only general statement about science that does not impede inquiry and prevent discoveries is 'anything goes' (1984:3). This attitude is not an excuse for irresponsible speculation, as anyone who has read Feyerabend knows. It is a statement of principle intended to keep open the doors of perception. It is a scientific principle designed to mitigate our natural tendency to allow epistemological presuppositions to determine what is perceivable or even seeable.

The pragmatic point of view is, for me, based on an observation. I observe that human beings spontaneously make up stories, interpretations about what we sense, perceive and know; and that whereas not all stories are equally appropriate to all goals, equally accurate in all situations, or equally beautiful, there is a place for all of them.[3] In short, the greatest danger comes when we confuse our own plausible fictions with reality and then to ignore other possible interpretations. Redding reading, giving fluid truth a plausible reality, is precisely the conundrum I hope to explore in coloring color--black and white.

Surrounding the conundrum is a *conflation*. To conflate means to "blow together...to combine into a composite whole." The study of color in the Western tradition of art and science is a composite of disciplines. In science the domain of color is part of optics; and optics, before it was opticks (a variant spelling Sir Isaac Newton, 1624-1727, used as the title of his book first published in 1704), was *perspectiva*. *Perspectiva* was mathematics, physics, physiology and sometimes the psychology of light and vision, all mixed up together. Johannes Kepler (1571-1630) gave modern optics its perspectivist stamp by conflating what, in the Middle Ages had been generally kept separate.

In art, the domain of color was dominated by painting, where Leon Battista Alberti (1404-1472) conflated *perspectiva*, *colore* and *istoria* in his treatise *On Painting*. It would be inaccurate to say of Kepler or Alberti that they were interdisciplinary. There was no such thing as "interdisciplinary" and from the beginning of the modern period[4] color is written about as a conflation, a veritable palimpsest of subjects from our contemporary point of view.

Most recent writers on color remark that color must be studied from an interdisciplinary point of view (see works by Boyer (1959), Gage (1993), Hardin (1988), Kemp (1990), Riley (1995) Wyler (1992), Zollinger (1972)) and generally they live up to their promise. "COLOR in Black and White" also presumes an interdisciplinary point of view but it should not be thought of in strictly disciplinary terms. I want to approach the study of color as a conflation among modes of perception. This approach

influences phenomenal observation. It alters intellectual presumption. It qualifies visual sensation in an hermeneutic circle. One can think of painting and physics, of psychology and philosophy, of vision and language, each as modes of perception. I fancy conflating these modes both "weakly" and "strongly."

Language and vision are conveniently opposite and call for a weak conflation. To call the work of Eleanor Rosch on the classification of color (1975, 1978), for example, a weak conflation is not to disparage her scholarship. She asks good questions and presents significant findings, but the vocabulary of presentation is specialized, a jargon, formed from the intra-disciplinary union of established academic domains, as biology was formed from Medicine, Natural History and Physiology (see Coleman 1985:2). A weak conflation creates a description that is more specialized, more precise and more accurate than any description possible in the parent disciplines.

A strong conflation, on the other hand, investigates the assumptions built into specialized vocabularies from outside that vocabulary, and it conflates concepts, ideas and methods so that no one discipline rules. For example, a critique of the language of color changes what we (think to) observe in color psychology, is changed by the range of new colors made possible through chemistry, is influenced by the current significance of color in physics, is altered by the modeling of drapery in painting, is transformed by the allegory of shadows thrown on a cave wall. These ideas are thematically linked. Some of them are intellectually contemporaneous and all of them are, finally, commensur-

able. They are commensurable for the simple reason that all of them are bonded (irrevocably) to us as a species, as communities, and as individuals through the phenomena of color.[5] The links are complex in the extreme but no activity that affects or is affected by our sensorium[6] can, in principle be excluded from the process of creating plausible descriptions.

"Color in Black and White" embraces this complexity and draws its examples from whatever domain offers a telling quote or pregnant observation to carry the argument forward. This kind of writing is dangerous since it runs the risk of presuming too much specialized knowledge of a general audience and omitting too much detailed information for specialists and there is a reward for the risk. The reward is a gentle reminder about specialization: we need specialists who specialize in being general. I think the "general specialist" is relatively common in architecture where there is a practical need for this peculiar form of specialty.

There is pressure upon bodies of knowledge to subdivide into ever more discrete packets of scholarly expertise. This is as it should be and generally is called progress; however, since progress ideally includes wisdom as well as information, the assimilation of knowledge as well as the assembly of data, we must insist on a broad perspective and a measure of integration if our scholarship is to be more than a body of technical expertise. Architecture, through the twin roles of aesthetic delight and technical fuctionality, is broad in this way. It is broad in layers.

A building is function layered with plan layered in

structure layered with mechanical and electrical subsystems. A successful building is layered in section, in elevation and in space. Finally, buildings are layered in economic, geographic and cultural milieu.[7] Making buildings requires broad expertise resolving conflicting requirements among different layers.

The practice of layering buildings is also a means of integration since it, as a practice, is alternately analytic and synthetic. In analysis define the problem, break it into its component parts and parse these out for solution. In the synthesis aggregate the solutions into a working model, make the model redundant to account for subtle unknowns and unforeseen problems of scale and build it. During all phases the role of the architect is to integrate disparate elements. She cannot possibly understand the minutia of every component of every sub-system, nonetheless she must be a specialist in forming parts into working wholes. Science, as a domain of knowledge, can be no less synthetic and building provides one alternative, home to the conflation of art and technology, home to conflation as a functional and finally humane practice for creating plausible descriptions--in color and in black and white.

Enriching the conflation is a question: "What constitutes the vivid perception of color?" In "Sunflower at Sunset Yellow," I endeavor to draw vivid yellow in words, to make one's ears serve for eyes.[8] Attempting to duplicate this synthesis in expository form, I devote much of the rest of the thesis to the question "What is vivid yellow?" Chapter three, "The Abstraction of Sight" develops the history of ideas about seeing, examining

the relationship between viewer and viewed in terms of abstraction, attraction and distraction. I argue that even though the historical development of ideas about seeing favors the intellectual abstraction of sight, phenomenal experience favors participation between the observer and the observed. I develop the idea that vividness, a type of participation balances abstraction through attraction and distraction.

Chapter four, "The Fallacy of Primacy" describes one important aspect of the relationship between and color and language. I argue that what constitutes a "primary color" is remarkably fluid and conclude with an exposition of the color terminology in art and science that surrounds the idea of primacy.

"The Layering of Color," Chapter five, develops a way of discussing vivid colors in the landscape. The landscape in this chapter is a painting by Claude Monet. I use Grainstacks (End of Summer) (1890-1891) to point out the complex set of visual competencies which human observers depend on to interpret scenes and pictures.

Chapter six returns to "Sunflower at Sunset Yellow" to test the schema developed in Chapter five and to present a plausible description of vivid yellow. Chapter seven, "Vividness in Architecture" develops the similarities (and differences) between a vivid experience of color and the vivid experience of a building using Balthasar Neumann's baroque *Church of the Holy Cross* (1749) at Neresheim as a test case.

In this whole analysis I assume that there is no intrinsic difference between the perception of "natural" objects such as a

landscape and the perception of "artificial" objects such as paintings and buildings. I assume that a vivid experience of landscape and a vivid experience of human fashioned spaces are not deeply opposed. Chances are that your favorite landscape is human fashioned and vividness is mind-made as well as contingent on 'external objects as existent things, realized in properties, qualities, actions, and relations--inherent in them and constitutive of them' (from Bliss, see above). Vividness is a signal we send ourselves that we have transformed the sensible into the substantial and I maintain the distinction between nature and artifice is irrelevant. There is no clear line of demarcation between the object of perception and the perceiver, and this is precisely what is exemplified in every vivid perceptual experience.

Vivid, the word, comes into English in the seventeenth century as a simple translation of the Latin vividus "to live" akin to "animate." The word has always referred primarily to seeing, even though it is now more generalized; used to describe anything that is "spirited, clear, fresh, or lively." Specifically related to color, vivid (in the second definition) means "brilliant; intense; bright; technically having a very high saturation." This second definition of vivid is why I am predominately concerned with saturation or the color of color. Finally vivid means to produce "distinct and lifelike mental images" "heard, seen, or felt as if real."[9]

What is interesting about the third definition is the phrase "as if real." "As if real" is a circumlocution that points toward an incongruity in the observation of ourselves observing. On the

most basic level it is the common recognition that sometimes our senses "lie" to us. They seem to report things that we know are not happening like the wet road mirage. As a consequence, we discount the information and get on with monitoring the world, constantly aware to potential danger. In a more difficult way the phrase "as if real" implies we that have evidence of the difference between seeing what is out there and seeing that it is an artifact of our senses. I have a tremendous amount of faith in this sort of introspective evidence, available through our perception of black, white and color.

Here, in the question, lies a *paradox*. Given that our senses are enormously precise, and that we often accept as accurate introspective evidence of the difference between perceiving what is "out there" and perceiving that is skewed by some external condition(s); why do we have no introspective evidence whatsoever that the rays of vivid objects are not colored?[10]

There are at least three possible explanations. (1) It is the wrong question. (I am currently convinced it is not the wrong question, but...). (2) The complex of experiment, theory, and warranted assumption called color psychophysics is fundamentally accurate and we can safely ignore contradictory introspective evidence about the nature of vivid color perception. In other words, according to the second option, the scientific models are true; which is to say that they answer more questions and predict more accurate results than any group of models yet proposed. (3) We may regard the apparent existence of a brightly colored world (in which we have no introspective evidence that vivid

objects are not colored) as a paradox. As Edwin Land said, in a different context "It seems to us...that this rationalization [that vivid objects are not colored in the point I am trying to make here] would be an oversimplification of the phenomenon and that it is better to keep wondering about it than to half-explain and then to dismiss it" (Land 1964:250)[11]. I regard it as a paradox, a live question and at least one scientist agrees, William D. Wright (b.1906).

William Wright, the British optical researcher who mathematically linked spectral sensitivity curves to the CIE (*Commission Internationale d'Eclairage*) 1931 chromaticity diagram, is also concerned with the transformation of the sensory into the substantial. In "Towards a Philosophy of Colour" (1965) he argues that our perception of space exists to make sensations real.

> For out of an incredibly intricate, gossamer-like system of light detection and of information-coding and decoding, and with no mental effort on our part, there emerges this stable, substantial end product--the material world we see around us. (1968:31)

For this conclusion Wright laid radical foundations: "I believe either the visual scientist or the colorimetrist" and "I now believe, the scientist's concept of colour is incomplete, that it is high time we developed a more adequate philosophy of colour to which both artist and scientist can subscribe" (p.26,7). I agree with Wright's prescription. Clearly he understood how color is rendered, even when it is rendered incompletely, in black and white.

Finally within the paradox is an *irony*--a rhetorical flourish in which "the intended implications are the opposite of

the literal sense of the words." "Color in Black and White" is, first, a narrative about learning to see color in color instead of through the filters: color in representation, color in language, color in history, color in the theory, color in science, or color in architecture. The irony? There is very little color to see in architecture and even less in architectural theory. I suspect this is due in no small part to a tradition established by Vitruvius in his disparaging remarks on color in *The Ten Books on Architecture*:

> The fact is that the artistic excellence which the ancients endeavored to attain by working hard and taking pains, is now attempted by the use of colours and the brave show which they make, and expenditure by the employer prevents people from missing the artistic refinements that once lent authority to works (1960:213).

In other words color may be applied for "brave show" to distract people from the "artistic excellence" (ancient) architects achieve, presumably in the truthful use of materials and the faithful copying of reality. Vitruvius, in short, advocates a use of color that makes it forever subordinate to the authority of form. Michael Graves' (b.1934) polychromy exists squarely in this tradition:

> One can think of the meanings ascribed to color as being derived primarily from associations found in nature. These associations are for the most part simple and somewhat commonplace...What we might call normal associations of color and material, found in construction and in nature, include red or terra cotta for brick, cream or ranges of white for limestone, travertine, etc. ranges of green for the general landscape, blue for sky, and so on. It is within this deliberately simple range that we start to identify the

> placement of such associative color values with that of form itself. (Graves in Riley 1995:216)

In other words the role of color in architecture is substantially subservient to the structure, form and materials of a building. Maybe this is as it should be. Maybe buildings *should* be chromatically subdued, especially on the exterior where the use of vivid color is often (and easily) condemned as garish. I doubt it, but I am not concerned with this issue in this thesis. What I am concerned with is the irony of studying color from within architecture and how, learning to see color changed the way I interpret architecture.

There is no easy way to describe what I am talking about. In one sense it involves interpreting surface independent of structure, or rather making no attempt to assemble oriented planes into homogeneous spaces. Considering color, considering architecture, I am convinced there is great value in not forcing scenes into their perspective resolution and of not allowing structure to determine the whole of architecture. What I am speaking of is a way of looking that is looking *with* the medium rather than *through* it. It is looking so as to infer the light context of the visual array from clues provided by objects that are sometimes curiously flattened and are always uniquely colored. It is a way of looking that cultivates naivete and it is analogous to a recognition of the difference between conventional, realistic, contour drawings where figure and ground are represented in their expected relations and "negative space" contour drawings where ground becomes figure and figure, ground.

Learning to look at buildings by learning to see color, is the difference between a "positive" reading of shape, form, structure and the "negative" reading of surface, color, light.

The irony of the absence of color in most buildings is that the best way to learn how to form immaterial light in material structure is through learning about the mechanisms of color perception, the nature of aerial perspective and the vagaries of object color. I begin with an analysis of the abstraction of sight and, in the end, "Color in Black and White" aims to color color, to color architecture, and to color black and white all with the vivid hues of a twilight insight.

Notes to Chapter 2

1. This quote is from the synonyms at "enigma" in Webster's Second ("W2" in the bibliography). All definitions are at the entry for the word in question from Webster's unless otherwise noted.

2. This long quote ends with a line I do not agree with and that I do not think is an accepted part of the definition of realism. I quote it here so that I may not be criticized for selectively misrepresenting Bliss's ideas. "...and that communal minds, and ultimately the general and the universal mind, must inherently subsist in the minds of associated and assimilated individuals" (p.171).

3. Patently false or even ridiculous stories have a role to play, even if it is only to make possible an appreciation of the simple and elegant stories that much more.

4. "Modern" as a term denoting an historical period is extremely problematic. It is problematic to period-ize history from a methodological point of view; but, more to the point, it is down right confusing from a practical point of view. In architecture "modern" was a stylistic designation associated with the early twentieth century practitioners Frank Lloyd Wright, Mies van der Rohe, and Le Corbusier. Nineteenth century novels display a flavor of heroic individualism once called "modern." Eighteenth Century science, in its own time was "modern"--an age when budding deterministic physics was the mirror of a clockwork universe. It is clear that each epoch in the history of the West has redefined modern according to its own ideas and preoccupations.

I prefer a more traditional definition of "modern." I use the term to refer to the period which comes after the "Middle Age" and re-animates the ideals of the "Ancients." Measured in centuries the modern epoch extends from the mid fourteenth century through the present. This is the meaning of the term as it was understood in the Renaissance, whose ideologues made up the designation to describe the third and final epoch in the history of the world. I assume, utilizing twenty-twenty hindsight, we can agree that the warp of Western history is mounted on an intellectual loom refurbished and rebuilt during the Renaissance.

5. The arrogance of this attitude is, indeed must, be tempered by the assumption that reality exists. The world pushes back and this is what saves us from solipsism.

6. "Sensorium" is a term intended to imply the necessary collaboration between interpreting and sensing in perception. It is meant to describe the eye/brain combination (the ear/brain combination, etc.) as the organ of perception. [I generally disregard taste as a distinct sense and prefer to link taste and smell together as "the chemical senses;" therefore, throughout this thesis the senses are four: visual, acoustic, tactile (or haptic) and olfactory (see fig.1)]

7. Some might say that there can be nothing integrated about the spheres of economics, ecology and craft but really what they are saying is that they do not approve of the current means of solving conflicts that arise among competing requirements. I say architectural schooling trains one to weigh and judge among competing necessities and that there is a technical name for this activity: It is called design.

8. The formula for the beginning of an *ekphrasis*, this particular version is from Charles Sears Baldwin (1959:18). *Ekphrasis* is technically a type of description that endeavors to give a voice to mute objects using highly patterned language with special attention to the corporeality of words. Like every story, it requires the reader's suspension of disbelief to be effective and it requires more than that. *Ekphrasis* is a rhetorical trope that begs to be heard and not just read.

9. From *The American Heritage Dictionary* (1969) at "vivid." The third definition in Webester's is equivalent but not quite as suggestive as the phrase "as if real."

10. This is a reference to the one passage that is always quoted from Newton's *Opticks* (Bk.I, Pt.II, Prop.II, Theor.II.) It is intended to evoke the edifice of warranted assumptions we call "visual psychophysics" or in this thesis just psychophysics. The whole quote from Newton is as follows:

> And if at any time I speak of Light and Rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly

> to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour. For as Sound in a Bell or musical String, or other sounding Body, is nothing but a trembling Motion, and in the Air nothing bout that Motion propagated from the Object, and in the Sensorium 'tis a Sense of that Motion under the Form of Sound; so Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays more copiously than the rest; in the Rays they are nothing but their Dispositions to propagate this or that Motion into the Sensorium, and in the Sensorium they are Sensations of those Motions under the Forms of Colours. (Newton 1952:124,5)

11. I quote Land here not for the specific support of an idea that he may offer but for the general point he is making about the role of unresolved paradoxes in all types of inquiry, especially in scientific inquiry.

THE ABSTRACTION OF SIGHT

> *The Chinese artist does not merely observe but identifies himself with the landscape or whatever it may be that he will represent. The story is told of a famous painter of horses who was found one day in his studio rolling on his back like a horse; reminded that he might really become a horse, he afterwards painted only Buddhas. An icon is made to be imitated, not admired...Such an identification, indeed, is the final goal of any contemplation--reached only when the original distinction of subject from object breaks down and there remains only the knowing, in which the knower and the known are merged. If this seems at all strange to us, whose concept of knowledge is always objective, let us at least remember that an "identification" was also presupposed in mediaeval European procedure; in Dante's words, "He who would paint a figure, if he cannot be it, cannot draw it."*
>
> *Ananda Coomaraswamy (1977:309)*

It seems prudent to begin this thesis with a definition of color and indeed I shall offer several definitions of color couched in the question: What is the physical context of seeing, hence that, of color? By the physical I do not mean the physiological. I intend something closer to the phenomenological in the sense in which Benjamin Kouwer uses the word:

> 'phenomenological' psychology or, as we shall hereafter call it phenomenology...strives to analyze the phenomena as integral parts of the situation as actually experienced. (1949:55)

The abstraction of sight, traces the history of the relationship between color stimulus and physical response in terms of its phenomenology. I choose my words carefully here for "trace"

means to draw, from Latin trahere, which combined with the prefix abs- in abstract means "to draw away," when combined with ad- in attract means "to draw towards" and when combined with dis- means "to turn aside." I will argue in this third chapter (1) that the history of theories of vision abstracts[1] the viewer from the viewed, (2) that psychophysics accurately describes the abstraction of sight (but not its attraction) and, finally, (3) that vividness tempers abstraction with the twin components of attraction and distraction.

Defining Color

Defining the word color is a tricky business. John Lyons defines it as

> the property of physical entities and substances that...makes it possible for human beings to differentiate between otherwise perceptually identical entities and substances, and more especially between entities and substances that are perceptually identical in respect of size, shape and texture. (Lyons, 1995:198)

This is about as general a definition of color as one is likely to get: differences in color are all that is left when everything else in the line of sight is indistinguishable. This definition reminds us that color is somehow intertwined with size, shape and texture; but, it does not say what color is. J.G. Brennan defines color as:

> A sensory or perceptual component of visual experience typically characterized by the attributes of brightness or lightness, hue and saturation; but in certain cases having zero saturation and so no hue... (1948:212)

Brennan's definition is interesting because he wishes to include black and white as well as red, green and periwinkle in the domain of color. I agree with Brennan that black, white and gray are colors2 but beyond this assertion and the naming of the attributes of color sensation (brightness, hue and saturation) he is not very descriptive.

Definitions of color proliferate; the *Commission Internationale de l'Eclairage*[3] and the Optical Society of America[4] offer definitions that are more technical. I will introduce some of the concepts on which these technical definitions are based; but, until they are situated in their scientific and/or philosophical context they are not very descriptive. Let us turn to an etymology of the word.

Color, the word used as a noun, has an interesting etymology. It was not adopted directly into English from Latin but derives through Old French color and the variant colour. What is interesting is that, according to both Eric Partridge and Webster's Second, Latin color is related to celare meaning to conceal. In other words color is cognate to hell, the underworld; hall, a covered place; husk, that which covers; housing, protective covering; cellar, a storeroom or secret place; occult, to cover over; clandestine, in secret; and through an extended form of its Indo-European root to klepto- a prefix meaning to steal. In other words color, in most Indo-European languages (according to its etymology), is not a facet that describes something funda-mental about objects but an attribute that hides important qualities. By definition, color is an

"outward semblance that disguises an object's real characteristics" and metaphorically is "the appearance or pretense taken as justification; a show of reason" (W2:9,10 at color).

Ancient Theories of Vision

This definition of color captures a persistent thread in the history of ideas about the relationship between observed and observer. Color masks the real properties of objects. This is, of course, an exemplary Platonic conceit. In Plato's hierarchy of the forms color is situated just above the lowest realm of appearance. Sight and the perception of color, belongs to the secondary causes of things "which, being devoid of reason, produce their various effects at random and without order" (Timeaus 46E). I will not dwell on Plato's idealistic philosophy5 except to note that Plato held an extromission theory of vision.

All ancient theories of vision assumed "that there must be some form of contact between the object of vision and the visual organ" (Lindberg, 1978:337). According to the extromission theory the eye sent forth rays that encountered an object of vision and somehow "felt" it.6 What is important about this theory is that its proponents, Euclid and Ptolemy, established an essentially mathematical theory of vision. Euclid established that the rays travel in straight lines. Ptolemy established that the rays form a cone of vision.

> [The] purpose was to offer a geometrical explanation of the perception of space...the theory was not designed with physical plausibility in mind; it was intended as a mathematical theory of vision, and it was to be judged by

> mathematical, rather than physical, criteria.
> (Lindberg, p.341)

The seeming implausibility of the extromission theory of vision contains a profound assumption, namely that the relationship between viewer and viewed is expressible mathematically in terms of the geometry of rays. Important to note is that the mathematical treatment of this relationship does not depend for its accuracy on an extromission theory of vision, since the geometrical relationships between object and eye hold whether the rays travel out from or in towards the eye.

Concerning the traditional view that color masks what is essential about objects, Aristotle (fig.2), in this regard as in so many others, was Plato's most cogent critic. In On the Soul Aristotle states:

> The object of sight is the visible, and what is visible is (a) color and (b) a certain kind of object which can be described in words but which has no single name...Whatever is visible is color and color is what lies upon what is in its own nature; "in its own nature" here means not that visibility is involved in the definition of what thus underlies color, but that that substratum contains in itself the cause of visibility. (in MacAdam, 1970:2)

Aristotle in this passage seems to be taking a position contrary to Plato's. In Plato, color "masks" important characteristics of an object perceived. In Aristotle color "expresses" what is visible, which is intrinsic to the object and which is an expression of some fundamental property of objects. Curiously, this idea about the function of color is not shadowed in any etymology or dictionary definition of the word.

Aristotle did not espouse a theory of vision diametrically opposed to Plato's, namely an "intromission" theory where rays from the visible object travel in towards the eye. He proposed an alternative somewhere in-between extromission and intromission theories. Lindberg calls it a "mediumistic theory" and defines it as when

> the visible object sends its visible qualities through the intervening air (or other transparent medium) to the observer's eye. Colored bodies produce qualitative changes in the transparent medium, and these changes are instantaneously propagated to the transparent humors of the observer's eye. Thus, a green object in some sense colors the observer's eye green, and this acquisition of color constitutes the act of seeing. The eye does not receive the visible objects, as in the atomistic [intromission] theory, but becomes the visible object. (1978:340)

Aristotle's theory of color is different from Plato's in two ways. First, for Aristotle, color expresses some vital quality of the object in the visual field and second, the sensing organ participates in the perception of color. Aristotle's idea of participation appears throughout his work. In the Metaphysics he says "thought thinks itself through participation in its object" (xii.7.8). This idea is profoundly foreign to modern readers, conditioned as we are by Cartesian dualism7 yet, it is critically important for us here.

In the Western tradition (even that part of it which is not mystical or medieval) there is ample justification for assuming observer and observed exist in the same frame of reference. Some recent scholarship (Crary, 1990) is concerned with showing how vision necessarily alienates the perceiver from the perceived

and historically disjoins object and subject. I hope to show how this disjunction, in color, is mostly a product of Hermann von Helmholtz'(1821-1894) nineteenth century psychology and the ways it is mostly not implicit in Albertian or even in Newtonian color theory. Furthermore; I will argue and that adopting a "participatory" phenomenological psychology is one half of the experience of vivid color. ..

Renaissance Theories of Vision

Leon Battista Alberti (1404-1472) was a looming presence in the Renaissance, in the history of Art History and in the Western preoccupation with representation. A subtle and powerful thinker, he opens his "commentary" On Painting with a plea:

> In this discussion, I beg you to consider me not as a mathematician but as a painter writing of these things. Mathematicians measure with their minds alone the forms of things separated from all matter. Since we wish the object to be seen, we will use a more sensate wisdom.
> (Alberti, 1976:43)

Alberti sets as the context of his commentary a "sensate wisdom," what we might call a phenomenology. He does this in order to differentiate the means of painting from other means of measuring the forms of things.

In the Prologue, Alberti sets out a tripartite scheme for his commentary. It is organized into three Books, one dealing with mathematics, one with the source of painting; one with art, "distinguishing its parts" and showing how the painter acquires "perfect skill and knowledge" (p.40). In the first Book Alberti

speaks of geometry with some authority. This is the book that contains his famous exposition of perspective as well as his controversial color theory. In the second Book he is at pains to show "that whatever beauty is found can be said to be born of painting" (p.64). Here he seems anxious to establish a new authority for painting and he does so by an appeal to classical rhetorical categories, using different names.8 In the third book he advises the painter on what "we" should know. This part is occasionally practical: make large drawings because small drawings easily hide weaknesses; squint your eyes to help evaluate the light quality of a scene; know how to paint "horses, dogs and all other animals and other things worthy of being seen" (Alberti p.94,5). Actually, the thrust of the third book is more speculative. Here Alberti speaks as a partisan of a theoretical position seeking to persuade painters that painting is equal parts geometry, good habit, learning, and beauty.

The question is: in what sense can it be said that Alberti (fig.4) is speaking as a phenomenologist? Much of the internal evidence seems to indicate that Alberti is speaking as anything but a phenomenologist. He speaks first as a mathematician then as an rhetorician, occasionally offering prescriptive advice then lapsing into pronouncements. But, I think Alberti was too powerful a rhetorician to state something obviously untrue and too subtle a stylist to rely on mere hyperbole.

Alberti's statements about the role of light in painting are the subject of James S. Ackerman's article "Alberti's light." Ackerman observes that Alberti's study of light and

color has been neglected in favor of his the description of perspective.

> I think there are two reasons for this bias: one, that the mathematical clarity of the perspective box appeals to the positivistic attitude of modern art history and is easily taught and discussed, particularly at a time when art is studied primarily from photographs; and two, that perspective could be represented as the paradigmatic invention of the Renaissance. (Ackerman, 1977:3)

I think that Ackerman's analysis is accurate. I also think that the reason Alberti's incremental extension to Filippo Brunelleschi's (1337-1446) idea of perspective is studied to the exclusion of Alberti's ideas about light and color has more to do with the fundamental scientific significance of the idea of homogenous space as opposed to the problem of optical representation. Alberti inherited a problem in painting--how to unify pictorial space--that was essentially an optical problem and solved it in terms of mechanics, the relation of bodies in frames of reference.

Alberti, by developing the equivalence of pictorial representation in a two-dimensional framework and spatial extension in a three-dimensional framework, actually unifies the space of the visual field and the space of the object, thereby implying the concept of a frame of reference. Therefore, Alberti is guilty by association of being a kind of proto-Cartesian, but this is not born out by his optical prejudices.

Alberti, writing on the cusp of the Renaissance is not unambiguously modern as Samuel Edgerton Jr. argues in his essay "Alberti's Colour Theory: A Medieval Bottle Without Renaissance

Wine." Edgerton argues

> Alberti, who had so neatly translated the optics of the visual pyramid into a workable construction for painters' layout of space, also apparently tried to apply the old colour theory to practice. He failed...For Alberti, in spite of his supposedly 'new' spirit, was still deeply rooted in the Middle Ages. (1969:110,1)

One might disagree with Edgerton that Alberti 'failed' to articulate a new color theory but his point--that Alberti was deeply rooted in the Middle Ages--is one well taken.

The invention of modern physiological optics was signaled by Kepler in 1604 partially by his discovery that an image, when it is passed through the lens of the eye, is inverted. Alberti had not a hint of this inversion. He believed, along with his Medieval predecessors, that the image is projected onto the front surface of the eye and is transmitted through the lens, without inversion, directly to the optic nerve which carries the image to the soul. Kepler argued that rays from the object travel through the pupil, are inverted by the lens, refracted at the boundary between lens and vitreous humor, and projected onto the retina which covers the concave backside of the eyeball (fig.5). He called the points of the one to one mapping of the object onto the retina "cones"8 since they are cones of light rays focused at the retina.

The point is that, for Medieval opticians and we can generally assume for Alberti, the image is projected whole and unaltered directly into the soul whereas for Kepler it is projected inverted onto the retina. Kepler does not speculate

further on the spiritual principles of vision, whether the image

> ...is made to appear before the soul or tribunal of the faculty of vision by a spirit within the cerebral cavities, or the faculty of vision, like a magistrate sent by the soul, goes out from the council chamber of the brain to meet this image in the optic nerves and retina, as it were descending to a lower court.(Kepler in Herrnstein, 1966:92)

but he is clear that the object, sensed as an image or pictura, is mediated by the iris, lens, vitreous humor and retina.

The significance of this difference between Medieval and Modern theories of vision is that for Medieval natural philosophers and for Alberti, the perceiving eye exists in the same frame of reference as the object perceived and as the perceiving "I," therefore; no matter how Modern (read mechanical) Alberti's perspective may be he still thinks the perceiver and the perceived are grounded in the same world. This is evident in his theory of vision, his theory of perspective. Finally, he affirms the interlacing of nature and its representation.

This belief is often discussed "within the Renaissance tradition of magic, in which to contemplate an object means to become one with it." Ernst Cassirer continues:

> But this unity is only possible if the subject and the object, the knower and the known, are of the same nature; they must be members and parts of one and the same vital complex. Every sensory perception is an act of fusion and reunification." (Ernst Cassirer in Crary, 1993:38)

Alberti is clearly proponent of this "magic" tradition. Except in one small way. Alberti supports the magical tradition by adopting a participatory phenomenology. It is slightly different than Aristotle's in that the active agent is the eye and the

soul of the observer rather than the visible object and its medium (this idea anticipates a general Renaissance preoccupation with the individual) and Alberti subverts the "magical" tradition by his imposition of a "frame" between the object and the picture.

> First of all about where I draw. I inscribe a quadrangle of right angles, as large as I wish, which is considered to be an open window through which I see what I want to paint. (Alberti, 1976:56)

The frame (and later the "net") through which one views the scene to be rendered, (as in Durer's often-reproduced engraving of a draftsman drawing an exposed female model through a gridded frame), although a heuristic device for teaching the techniques of perspective, drives the first small wedge between the observed and the observer. But the frame is not and was never intended to disjoin the viewed and the viewer.

In other words, for both Aristotle and Alberti, seeing is a mechanism through which the observer participates with the object of perception. In retrospect, from a contemporary point of view where objects are presumed to be totally distinct from their internal visual representation, it seems as though Alberti's window abstracts subject from object; but this is a relatively recent development in the history of ideas about seeing, based on a misconception about Renaissance epistemology. Furthermore, the window remains open in the work of Sir Isaac Newton (1624-1727).

Enlightenment Theories of Vision

Sir Isaac Newton (fig.6), working very much in the tradition Kepler established, did not necessarily support the absolute distinction between the seeing eye and the object perceived. How can this be so, given that Kepler disjoins the observer and observed through his discovery of the inversion of the optic image by the lens of the eye? The short answer is that Newton, using his discovery of a mathematical treatment of color, seems to think that the relationship between the sensation of color and the objective facts of color were in perfect correspondence. The long answer is not much longer, so, before we consider the evidence, let us examine the context of Newton's discovery.

Even though Aristotle's authority as a natural philosopher was progressively diminished beginning in the early Renaissance, his doctrines, though discredited by most enlightenment thinkers, still exerted an influence through scholastic philosophy.9 Scholastic philosophy distinguished between two kinds of colors. Following Aristotle's lead in Meteorologica there "emphatic" or "apparent" colors, produced by the juxtaposition of light and darkness, which are the colors of rainbows and prisms and following Aristotle in de Sensu, there were "real" colors, displayed by lighted bodies. This distinction is preserved in current color theory by the concepts of "illumination" and "object" color (respectively); but, today both kinds of color are known to be subsets of the same phenomena. Rene Descartes (1596-1650) was the first philosopher to conceptualize color in this way. Descartes effaced the absolute distinction between "apparent" and "real" colors: "All colors were apparent, and thus all

colours were produced the way prismatic colours were." (Schaffer in Shapin, 1984:74)

Descartes contribution to the study of color was his geometrical demonstration of the position of rainbows relative to observers, by the application of Snel's law of refraction. It is called Snel's law after the Dutch mathematician Willebrord Snel van Royen (1580-1625) who published it in 1621; but A.I. Sabra presents evidence, now generally accepted, that Descartes and Snel arrived at the formula independently. The law of refraction mathematically describes the bending of light upon passing from one medium to another. It is given by the formula $n' \sin i' = n \sin i$, where n equals the refraction index of the medium and i equals the angle of incidence measured from the normal of the boundary between media (from van Heel & Velzel p.31, fig.7). Descartes used this law to explain, in a quantitative manner, why the band of the rainbow appears where it does as well as the appearance of the secondary bow.

> So that there is a shadow bordering on both sides of the light which, after having passed through an infinite number of rain drops illuminated by the sun, comes to the eye at an angle of 42 degrees, or a little less, and gives rise to the first principal rainbow. And there is also a shadow terminating [the light] which comes at an angle of 51 degrees, or a little more, and causes the exterior of the rainbow; for, not to receive any rays of light in one's eyes, or to receive considerable less of them from one object than from another near it, is to perceive a shadow. (Descartes in Sabra, 1981:67)

Descartes' conceptual breakthrough is laudable, but note the hint of an Aristotelian formulation of color as the juxta-

position of light and shadow. The fact is that Descartes never managed to found a mechanical theory of color, per se. As Richard Westfall observes:

> In formulating his theory of colors Descartes self-consciously played the rebel, casting out the peripatetic [Aristotelian] doctrine of qualities and colors in order to substitute a mechanical explanation. Little did the rebel comprehend how closely the bonds of tradition still confined him. (1962:342)

As a consequence of the mathematical robustness of Descartes theory of the rainbow and of the incomplete nature of his theory of color, "[c]olor became virtually a test case of Cartesian metaphysics as it applied to qualities." (Westfall p.340)

Now, for Descartes there were two kinds of qualities, the qualities of local motions that 'excite sensations' and qualities that observers can form from 'clear and distinct ideas.' Colors are so-called "secondary qualities" that excite sensations. The motions of atoms in light are primary qualities which we can form from 'clear and distinct ideas.' Newton follows Descartes' lead with respect to the idea that colors merely excite sensations.

> And if at any time I speak of Light and Rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour. ...so Colours in the Object are nothing but a Disposition to reflect this or that sort of Rays more copiously than the rest; in the Rays they are nothing but their Dispositions to propagate this or that

> Motion into the Sensorium, and in the Sensorium they are Sensations of those Motions under the Forms of Colours. (Newton, 1952:124,5)

This is to say that color does not exist in bodies that are colored but exist only as a code for the sensorium, the human eye/brain sensing apparatus. In so far as Newton accepts Descartes notion that colors merely excite sensations, he contributes to a mechanistic tradition that divides our perception of the world into primary qualities that are knowable and secondary qualities that are artifacts of the act of perception. On the surface of it Newton's discovery that 'the rays are not colored' refutes the Aristotelian position that, in terms of color, "thought thinks itself through participation."

For Newton, it seems, there is no participation of the mind with already colored phenomena because the mind alone supplies phenomena with color. This conclusion about Newton's views, though, is a bit hasty. Although Newton was critical of the Aristotelian tradition that did not distinguish between primary and secondary qualities, nowhere in the Opticks (fig.8) (or as far as I have been able to discover in the rest of Newton's voluminous optical papers) did he specifically uphold the distinction between primary and secondary qualities. As Dennis Sepper argues in his guided tour of Newton's Optical Writings:

> Insofar as the primary-secondary distinction implies that the primary qualities reveal something proper to the thing itself whereas the secondary only reveal the character of the interaction of a hidden property of the thing with the perceiver, Newton seems to hesitate. Perceived colors, at least in certain circumstances, stand in a very close

> connection with fixed characteristics of rays of light and...with the fundamental arrangement of matter in bodies, too. (1994:94)

For Newton, then, color is an expression of "a basic entity revealed." So argues A. Rupert Hall:

> The essence of the Newtonian theory of colour (and hence of light) is that true colours always exist, just as atoms always exist, and cannot by any process be created (except by the creation of white light). The rays are the colours and the colours are the rays, or to be more physically exact the property of the ray that we perceive as a colour is indissolubly part of it and cannot be altered. (1993:17. All parenthetical remarks by the author unless otherwise noted.)

In other words, Newton's refutation of the scholastic formula that "the sensible in act was the same as the sense in act" (Sepper, p.94) does not really differ from the Aristotelian tradition that conceptualizes color as an expression of some fundamental characteristic of the object perceived. Newton's discovery that white light is comprised of colored light, differently refracted

> leads naturally to the idea that refrangibility and color are not just closely correlated but [are] perhaps even results of a common cause, a single underlying reality. It is therefore quite conceivable that color is just as objective a quality as is refrangibility. (Sepper p.90)

The unity of an underlying reality with perceived reality followed from Newton's discovery that the science of colors mathematical.

> Since an exact science of them (colours) seems to be one of the most recalcitrant things that is lacking in Philosophy, I hope to show--as it were by my example--how valuable

> mathematics is in natural philosophy; and on that basis I can exhort geometers to investigate nature more rigorously, and those who are desirous of understanding nature to take up geometry first...So that, by the efforts of philosophical geometers and of philosophers employing geometry, we may bring to birth a natural science confirmed by the strongest of evidence, in place of the conjectures and probabilities that are everywhere bandied about (Newton in Shapiro, 1984:87,439)

This mathematical/geometrical treatment of light is slightly at methodological odds with Kepler's basic findings. Where Kepler's theory is a physiological theory in that it takes into account the physical fact of the eye's inversion of the image in the optic array, it is still mostly a mathematical theory of vision in the tradition of Euclid and Ptolemy. Newton's mathematical theory is subtly different. Rupert Hall considering the opening sentences of the Opticks argues:

> Evidently Newton prefers the similitude with matter-theory: the ray is a least part, just as an atom is the least part of matter. It is not a line because that is continuous, whereas light, Newton says, is discontinuous, that is, it is a physical entity not a mathematical abstraction. ...Hence from the first Newton was making provision for, not the abandonment of geometry in favor of the qualitative language in which colour had traditionally been discussed, but the greater complexity of geometrizing light-rays when they were no longer to be treated as physically uniform and homogeneous. (Hall pp.94,5)

In the end Newton's color theory implies a phenomenology of vision that situates the observer in same frame of reference as the observed. Newton's theory is quantitative where the earlier theories had been qualitative, but he still thinks observers observe a fundamental characteristic of objects when they sense

colors.

Through the end of the seventeenth century Newton's optical ideas were hotly debated and not widely accepted, particularly on the continent, where no qualified experimenter was able to reproduce his results. By the time the Opticks was finally published in 1704, however, the optical controversies were played out and Newton's optical work was beginning to be accepted. This was due not so much to the force of argument in the Opticks but to the prior publication of Principia. It is interesting to note that in the eighteenth century, as experimental science came into its own, Newton's ideas about experimental method combined with Alberti's notion of the frame, contributed to an increasing abstraction of the treatment of light and sight that neither author espoused in their own work. I am referring to A. Langen's concept of rahmenschau or "frame vision."

Frame vision "is a rationalistic, didactic limitation of the field of vision to the tiny area of acute perception." In the eighteenth century, "the eye was was strongly predominant among the senses, as it has been in others; but people used their eyes in a peculiar way which was connected with their very conception of life." (precis of Langen in Skard 1946:183). Alberti's contribution to frame vision is obvious. His rectangular frame, originally intended to delimit the scene to be painted as a whole, is didactically shrunk till seeing is confined to the "tiny area of acute perception."

Newton's contribution to frame vision is a bit more obscure but can be traced through the notion of "virtual wit-

nessing" that Steven Shapin argues was part of the production of knowledge in early experimental science. While Newton provided the mathematical grounding of experimental science his older contemporary and long-standing correspondent Robert Boyle (1627-1691) propounded conventions for the communication of scientific knowledge.

> Elaborate sentences, with circumstantial details encompass-ed within the confines of one grammatical entity, might mimic that immediacy and simultaneity of experience afforded by pictorial representations. (Shapin, 1984:493)

Boyle was, in other words, privileging visual perception in testing for truth. Therefore, both writers, Alberti and Newton, however unwittingly, contributed to the predominance of vision in the eighteenth century and the notion of frame vision. At the beginning of the nineteenth century the frame that separates observer and observed was still open but it was closing fast.

Nineteenth Century Theories of Vision

If rahmenschau was indeed a dominant principle in the eighteenth century scientific and artistic culture, its physical analogue was shortly to be discovered. Ludwig Hermann von Helmholtz (fig.9) in his Popular Scientific Lectures describes it thus:

> There is in the retina a remarkable spot which is placed near its center, a little to the outer (temporal) side, and which from its colour is called the yellow spot. The retina is here somewhat thickened, but in the middle of the yellow spot is found a depression, the fovea centralis, where the retina is reduced to those elements which alone are absolutely necessary for exact vision. (1962:101,2)

Von Helmholtz' discovery of the fovea centralis (fig.10) seemed to vindicate the "frame vision" upon which he would build a rigorously abstract psychology of sight.

Von Helmholtz was a towering figure in nineteenth century science (fig.11). The mathematician W.K. Clifford may have summed it up best when he described von Helmholtz as "the physiologist who learned physics for the sake of his physiology, and mathematics for the sake of his physics, and now is in the first rank in all three" (in Kline in von Helmholtz p.vii). Von Helmholtz was in an excellent position to speculate on the relationships among different branches of science, doubly so, for this brilliant mind seemed to be as at home in philosophy as in physiology, in physics as in painting. His solution to the problem of the nature of vision was ingenious. He simply separated the world into what is objectively knowable, by mathematical means in physics, and what is subjective, knowable in relative terms in psychology.

> The physiology of the senses is a border land in which the two great divisions of human knowledge, natural and mental science, encroach on one another's domain; in which problems arise which are important for both, and which only the combined labor of both can solve. (von Helmholtz p.93)

This separation between natural and mental science is the foundation on which von Helmholtz built his color theory.

Von Helmholtz contribution to physics was decisive. He formulated the conservation of energy principle which he describes as:

> the conclusion that Nature as a whole possesses a store of

> force which cannot in any way be either increased of diminished, and that therefore the quantity of force in Nature is just as eternal and unalterable as the quantity of matter. Expressed in this form, I have named the general law "The Principle of the Conservation of Force" (von Helmholtz p.72)

Von Helmholtz formulated this principle as a young man working in a research laboratory fitted out in an army barracks. It was formulated in response to a biological controversy. The question of vitalism, whether organisms are ruled by physical and chemical forces or whether there is a vital force in an organism that controls these forces, was hotly debated in the nineteenth century. When the question was posed as a biological issue, von Helmholtz performed an experiment that measured the caloric intake of an organism against its heat output. He discovered that they matched exactly and on this basis formulated the principle of the conservation of energy (which applies to all energy in the universe).

Having discovered that there is no "vital" force operating in organisms von Helmholtz turned his attention to visual perception. The results were published in three volumes titled the Handbook of Physiological Optics (1867) and were summarized the next year in a course of lectures titled "The Recent Progress of the Theory of Vision." The exposition below draws on von Helmholtz' summary.

Von Helmholtz' distinction between physical and psychological process was an astute philosophical move, recalling Descartes mind-body dichotomy. By concentrating on the boundary

between what is knowable in physics and what is knowable in psychology von Helmholtz created a domain of inquiry called "psychophysics." Psychophysics distinguishes the certainty and objectivity of physics from the uncertainty and subjectivity of psychology, but the separation is not absolute. Psychophysics is a borderland, where the objective mathematical methods of physics merges with the subjective psychological domain of perception (fig.12). In order to distinguish the part of psychology that can be rendered scientifically--mathematically--certain from the part that remains beyond the reach of mathematical physics, von Helmholtz echoes the division between physics and psychology in the division of visual processes into "sensation" and "perception." This distinction is operative in all sensory process, not just vision, and from it he draws a most important conclusion.

> [T]he kind of sensation which will ensue when we irritate a sensitive nerve, whether an impression of light, or of sound, or of feeling, or of smell, or of taste, will be produced, depends entirely upon which sense the excited nerve subserves, and not at all upon the method of excitation we adopt. (von Helmholtz p.121)

In other words physical cause and perceptual effect are completely disconnected since the perceptual effect depends entirely on the identity of the system of nerves which delivers the sensation to the brain. von Helmholtz borrowed this idea from Johannas Muller (1801-1858) and illustrates it with the example of light. Light is not a physical cause of seeing since the impression of light can be delivered to the brain by pressing

lightly on the eyeball with the eyelids closed, therefore; there is no causal connection between light and seeing. Muller developed this idea with more scientific rigor in his psychological work but it fell to von Helmholtz to develop the philosophical ramifications of it in the epistemological ruminations that accompany his physiological research.

Furthermore, for von Helmholtz, there is no overlap among the different senses.

> The most complete difference offered by our several sensations, that namely between those of sight, of hearing, of taste, of smell, and of touch--this deepest of all distinctions, so deep that it is impossible to draw any comparison of likeness, or unlikeness, between the sensations of colours and musical tones--does not, as we now see, at all depend upon the nature of the external object, but solely upon the the central connections of the nerves which are affected. (von Helmholtz p.139)

Even though vision, like hearing, is divided between sensation--the action of the impression of objects in the physical world--and perception--the "higher brain function that 'interprets' (though von Helmholtz does not use this word) sensory data, there is no link among sensory modalities. Even though the idea that there is no connection among sensations has subsequently been modified by research conducted into synesthesia10 von Helmholtz' basic position is still accepted as true. In short, for von Helmholtz there is no necessary connection between physical cause and perceptual effect.

> [T]here is really no meaning in talking of properties of light which belong to it absolutely, independent of all other objects, and which we may expect to find represented

> in the sensations of the human eye. The notion of such properties is a contradiction in itself. They cannot possibly exist, and therefore we cannot expect to find any coincidence of our sensations of colour with qualities of light. (von Helmholtz p.142)

Two of von Helmholtz further considerations are worth noting. The perception of depth for some reason he does not explain, is exempted from the lack of an exact (perceptual) correspondence between observed and observer.

> Here, again, as in the system of colours, the outer world is richer than our sensation by one dimension; but in this case [of depth] the conception formed by the mind completely represents the reality of the outer world. (von Helmholtz p.158)

In other words, the fact of depth is accurately given in perception where as the perception of color is one dimension "flatter" than physical color.

The second position of von Helmholtz' worth considering is what is might be referred to as his scientific "chauvinism." where man's telos is the conquest of nature, but it is worth calling attention to. Von Helmholtz says:

> we cannot triumph over the machinery of matter by ignoring it; we can triumph over it only by subordinating it to the aims of our moral intelligence. (von Helmholtz p.21)

This quote nicely sums up von Helmholtz' belief that where man's telos is the conquest of nature. Von Helmholtz says it is a divide and conquer strategy for the creation of psychophysics. Actually "divide and conquer" is a little too simplistic a characterization of his approach. I would call it divide and subordinate" and "divide and define." I have drawn attention to the

first round of divisions above: divide central from peripheral vision, divide the natural from the mental, divide life from vital agency, divide physical cause from perceptual effect, divide the senses from each other, divide light and color, divide spatial vision from color vision, divide physics from psychology, and most importantly divide sensation from perception. It could be argued that it is the very method of science to draw distinctions within concepts to the finest degree possible and that many of the distinctions von Helmholtz drew did not originate with him. For instance, the distinction between light and color. Newton relied on this division as did Alberti when he distinguished between dark/light and color. Similarly Descartes had distinguished the mental from the physical. But none of these thinkers so consistently relies on divisions among related concepts in order to make progress. This is one of the reasons
von Helmholtz' work stands as the noteworthy culmination of the increasing abstraction of sight.

Other examples can be found in what he subordinates and what he ignores. Von Helmholtz subordinates psychology to physics and then, paradoxically, ignores physics. He subordinates psychology to physics by discovering a way to bring the tools of mathematical physics into psychology, rendering a portion of psychology mechanical in the sense that truth and accuracy are judged according to the rules of experiment and the calculus. He ignores physics because, as Newton correctly observed, there is no color per se in physics. Von Helmholtz

subordinates sensation to perception and ignores the role of hearing, touch, taste and smell in vision. He subordinates sensation to perception not only for visual scientists but de facto for ordinary people, by leaving out most of what is commonly thought to be the complexity, the beauty, the mystery in perception and making sensation prosaic--somewhat perceptions usurper--the sole domain of what is knowable. He ignores information from other senses in the construction of the mechanism of sight by assuming that since the neural channel determines the sensation and because there are no hard wired connections among the channels, that hapticity, for instance, plays no role in vision.11

Furthermore, von Helmholtz subordinates cause to effect by assuming that causes are plural and unknowable and effect are singular and, at least at the level of sensation, mathematically describable. He forgoes a detailed examination of the physical world, partially for the same reason he subordinates physics but mostly because it is simply not within the domain of his interest in the Physiological Optics. Finally he subordinates color vision, though he has much to say about it, to spatial vision and ignores peripheral vision altogether. Color vision is "of the plane dimensions of the field of vision" (p.158) whereas depth perception is constituted of higher dimensions. More importantly, our spatial sensations coincide 'exactly' with what is sensed while color only corresponds approximately. Perhaps most tellingly, von Helmholtz is primarily concerned with the 'sweet spot' of visual sensation, the fovea centralis. He all

but ignores the contributions of sensors outside the area of acute vision in the perception of color.

For all of the scorn recently heaped upon the scientific method for its divide and conquer mentality, and for the portion of this scorn that belongs to von Helmholtz for his divide and subordinate and ignore method, one must ask the question what do we get in return for this, admittedly divisive, methodology. What we receive in return is extremely valuable. We get a powerful predictive tool with technological implications, and we get an accurate descriptive tool that, within the confines of its stated limitations, actually describes the physical and physiological context of color very well. We get a predictive model of color blindness and we get a technical vocabulary and color theory that has lead to ever more precise ways to communicate acceptable color tolerances in the manufacture of goods, without reference to a chart of colors.

There is a trade off, of course. Von Helmholtz' psychophysics, in rendering sensation mathematical, radically disjoins observer and observed, solidifying what I have referred to as the abstraction of sight. In this case von Helmholtz may have been acting as an agent of his time, since the alienation of the individual was such a prevalent theme in nineteenth century fiction; but in another sense he was a leader, for in bracketing off what is not mathematically demonstrable from what is, he was able to bring much clarity to the confusion of perceptual effects.

The most important way he accomplished this was through the

creation of a vocabulary in which the effects of color may be precisely described and categorized. In this vocabulary von Helmholtz defines the physical context of seeing color very comprehensively. Though I may not agree with all of the implications inherent in this systematization, it is still the most comprehensive vocabulary available for an analysis of color perception. The following exposition defines hue, brightness and saturation as they are currently understood and relates these definitions to the words von Helmholtz used in order to dispel some of the more pervasive confusions that arise from the plethora of words used to describe the effect of color by artists, historians, and psychologists. The vocabulary of psychophysics is important because it provides us with the basics--the tools--for a discussion which will ultimately yield a broader and more subtle view of color phenomenon; the full experience of color in everyday life I am looking for.

Vocabularies of color description in painting and psychophysics

First von Helmholtz divides the experience of color into three objective differences, what have come to be called "attributes of sensation."

> In this way we may reduce all possible actual (objective) differences in colour, so far as they are appreciated by the eye, to three kinds; difference of hue (tone), difference of fullness (saturation), and difference of amount of illumination (brightness). (von Helmholtz p. 130)

These differences are not without precedent. von Helmholtz was an acute observer of painting, as well as physiology (demon-

strated in his essay "The Relation of Optics to Painting," 1962) and I suspect the attributes of sensation--brightness, hue and saturation--owe part of their meaning to painters' (and art historians') vocabulary of description for the use of pigments, namely "value," "color" and "intensity." I intend to use the color vocabulary of painters to explain the vocabulary of psychophysics and the terminology of science to make sense out of the terminology of art (fig.13), in this process illustrating the ways psychophysical concepts differ from painter's.

Color in painters' terms--hue in von Helmholtz' terminology--is a strictly qualitative aspect of perceiving objects

in the context of illumination. Saying color is a quality is like saying color is a mystery. The mystery of color is the

> mystery of the colour sensations themselves. What is redness? What is greenness? We simply do not know. We cannot describe them in terms of any any other parameter. (Wright,1967:43)

Hue is the difference we are discussing when we speak of an object being yellow not orange, red not scarlet, purple not violet, green not blue. According to Albert Munsell (1858-1918), the great color classifier, hue is "that quality by which we distinguish one color family from another" (Munsell,1915:15). This definition stands somewhere between painters' notion of colors and the psychophysical concept.

In order to make this point, assume that a painters' concept of color is limited by the technology of paint manufacture. Where the limits of this technology are adequately described by

a relatively small family of natural pigment colors, roughly analogous to red, yellow, green and blue in the early Renaissance. By the nineteenth century many more natural and synthetic raw materials suitable for pigments had been discovered, so the distinction between red and scarlet could then be described as a difference in color. The same situation occurs in psychophysics today where a difference between two kinds of equally saturated reds is considered a difference in hue. What is important from von Helmholtz' work is that colors can no longer be described according to a single variable called "color" and requires the creation of other, more precise terms which are used in combination to describe the sensation of color accurately and with precision. For the remainder of this essay I will use the word "color" to refer to a plurality of sensible variables mixed up in a perceptual experience of color. I will use "hue" to refer to the sensation that isolates the experience of red from scarlet, of green from blue, and so forth without much ado.

Value (fig.14) is often discussed by analogy to the amount of white or black pigment added to a color straight from the tube, so to speak. Two qualifications are necessary. First, some hues are intrinsically lighter or darker than others. Purple is intrinsically darker than yellow, orange is intrinsically lighter than blue. Red and green are, in terms of intrinsic lightness, about equal. Therefore; one may describe the intrinsic value of hues without preference to the amount of white or black pigment added to a particular color. Second, the extrinsic value, or just the value, of a color can be conceptualized as

the addition of white and black to a pigment, but it is important to note that painters sometimes create hues by the mixture of two chromatic pigments and this mixture affects the value of the final color. If the mixed hues differ in intrinsic value, the resulting hue will be of an (only generally predictable) value, different than either of the original hues. Yellow (high value) + blue (low value) = green (medium value).

Brightness, though in some sense the degree of lightness in color, is not particularly analogous to value. The concept of brightness is founded in Descartes' conceptual shift that concentrates on the role of light in color. Brightness is a measure of the relative amount of light in a scene and not an absolute measure of the amount of white or black pigment.

The character of brightness as a relative measure of lightness may become clearer when we consider how the sensation of brightness is skewed in the perception of objects. The effect is called brightness constancy. Consider the perception of chunk of charcoal in bright sunlight and a piece of typing paper in deep shade. Objectively the piece of paper might be radiating less light per unit area than the piece of charcoal in bright sunlight, Yet, the charcoal is perceived as being black and the paper is perceived as white. How does psychophysics account for this simple perceptual fact? Partially by separating sensation from perception, measuring the amount of light relative to the sensitivity of the retina, and leaving brightness constancy to be explained as a "psychological" effect. Brightness, then is the "attribute of visual sensation according to which an area

appears to emit more or less light" (CIE 45-25-210 in Hardin, 1993:210)

Brightness, in effect, reintroduces the scholastic distinction between apparent and real colors, which never really went away. Psychophysics merely reversed their priority. Instead of apparent colors, i.e. the rainbow or the color of light, acting as a subset of real color, as the color of objects, light determines the color and appearance of objects and in its paradigmatic case may be studied without reference to bodies. Brightness replaces a scale of value determined by the reflectance of objects with a scale of the sensation of contrast determined relative to the built in sensitivity of the eye to contrast and to neighboring objects. This is a profound idea since it assumes that all 'the eye can possess is light',[12] essentially dematerializing objects as sensations and objectifying light as the material of sensation.

Brightness is measured on a scale that grades from dim to dazzling, where any perception on the scale is conventionally referred to as "gray" but this is not the gray of painters, it is the grey13 of psychophysicists and it is not a property of objects or even of an isolated light. The sensation of grey is a product of contrast, similar to the charcoal and paper in the above example. Brightness as the visual scientist Ralph Evans defines it is:

> the relationship of the stimulus to its surround. It is not wrong to say that the gray and the black [in a scene] are produced by the surround and not by the stimulus itself although, of course, the stimulus determines how much gray is seen. In other words, gray does not have any single,

> simple physical counterpart in the stimulus. It is caused by the interaction in the mind of the relationship of the stimulus to its surround. Gray is not a physical entity, or object, however much it may appear so. (Evans,1972:56)

In all fairness I should point out that although Evans' definition of brightness is not controversial he goes on the ascribe a significance to the production of grey in this way that is not generally accepted.14

Qualifications of Evans' definition of brightness in the context of the perception of grey (and gray) aside, it is strictly a difference in brightness that, in the story of "Sunflower at sunset yellow," accounts for what happens when the yellow of the sunflower petal is juxtaposed with the orange of the setting sun. The flower, which seemed every bit as bright as the sky when the two were not contiguous, is easily overwhelmed by the sky when the two are observed side by side. This is a difference in what is called brightness and the point is that, just as Newton made colors a code for the sensation of light energy, brightness makes grey a code for the sensation of contrast.

Saturation is the last term which remains to be defined, and its analogy to intensity, in painters terms, has created a pervasive confusion and a disassociation of conceptual tools that makes it difficult for painters and psychophysicists to converse. Intensity, though not a technical term in physics, is used to describe the idea of flux, unit energy per unit area and unit time. Unit area is sometimes measured as the solid angular subtense of the rays as they flow from a surface or point

source, as in "radiant intensity" and "radiance," or it is sometimes measured as the unit area of the body that the energy is radiating onto, as in "irradiance" and its psychophysical correlate "illuminance," but area is always taken into account in the physical evaluation of the "amount" of light (fig.15). This follows from the inverse square law of energy in the propagation of light and it should be clear that intensity, insofar as it is a physical term at all, refers to brightness. But intensity, for painters, refers to what some describe as the color of color, and it is a reasonably close approximation of the sensation von Helmholtz called saturation.

In painters' terms, a saturated color is a color of the highest concentration possible, in other words colored pigment straight from the tube. It works this way. Pigment straight from the tube is more saturated than pigment mixed with any other pigment, chromatic or achromatic; and powdered pigment appears more saturated than the same pigment mixed with the medium that must be used as a vehicle for dry pigments. For instance, combining viridian (a species of green) and white, or gray, or black diminishes its saturation. Likewise one cannot mix viridian by combining cobalt blue and cadmium yellow because a good quality viridian is already fully saturated and any mixture of two chromatic pigments diminishes the saturation of the resulting hue. Finally, mixing dry pigment into the vehicle that allows one to paint also diminishes the saturation of the pigment. Cheap paint manufacturers use filler, in place of more pigment in the vehicle, thereby desaturating the color.

Even quality manufacturers of painters' pigments suffer some diminution of saturation in their product, since anything added to pure pigment diminishes its saturation.

Saturation in psychophysics works much the same way as it does in painting with the, by now, obvious proviso that it refers to the subjective sensation of light. Evans goes to the heart of the difference.

> Saturation is an unfortunate word in this context since it implies a similarity to saturation in chemistry which has a definite maximum at which a given solution is said to be saturated with the solute. There is no similar saturated maximum in color. A better chemical analogy is concentration, and it is helpful to think of color saturation as concentration--hue per square inch, if you like. (p.52)

Saturation has no well-defined upper limit (as it does in the pigment analogy used above). The reason is that it is possible to perceive a hue as being more saturated than any color could, in fact, be. Von Helmholtz is very well aware of this effect (as, of course, are painters):

> We need then only assume that actual coloured light does not produce sensations of absolutely pure colour; that red, for instance, even when completely freed from all admixture of white light, still does not excite those nervous fibers which alone are sensitive to impressions of red, but also to a very slight degree, those which are sensitive to green, and perhaps to a still smaller extent those which are sensitive to violet rays. If this is be so, then the sensation which the purest red light produces in the eye is still not the purest sensation of red which we can conceive of as possible. (von Helmholtz p.136)

The effect of the 'purist sensation of red' is a contrast effect of the mechanism doing the sensing and it is called color con-

trast, (though it might more accurately be called hue contrast). Simply stated, a color is perceived as more saturated when it is brought into a mutually enhancing relationship with certain other hues. This is a well-known result of the juxtaposition of complementary colors which makes each color appear more saturated than when the colors are viewed in isolation.15 The point is that von Helmholtz is able to account for the effects of color contrast by virtue of the double distinctions he draws, first between physics and psychology and second between sensation and perception.

If saturation has no clear upper limit as defined by the colors of objects in the real world, its lower limit does exist. Although it is also a source of minor confusion for typically, zero saturation is discussed as grey but, strictly speaking, this is inaccurate since grey is itself an effect of contrast. Therefore, though the lower limit of saturation may be thought of as a gray, it is technically a sensation of 'indeterminate hue (Evans,1972:52). Let me explain by analogy to a pigment color system.

The pigment color order system of Munsell is constructed based on the idea of equal perceptual steps among all colors on three axes, but it is not a fully articulated three dimensional space. The reason for this has to do with the concept analogous to saturation in Munsell. Munsell calls saturation "chroma" and it is a measure of the concentration of color at a specific value (fig.16). In other words the space is layered. It is layered on the basis of a scale of grays stretching in ten equal

perceptual steps between black (on the bottom) and white (on the top). Munsell uses the intrinsic value of unmixed hues to distribute them in a corresponding (hierarchical) fashion. Yellow is intrinsically light so fully saturated yellow occurs at the level of gray eight, counting from the bottom. Blue is intrinsically dark so the plane of value that contains the blue of maximum chroma is level two (fig.17). Fully saturated yellow on plane eight is related to fully saturated blue on plane two, but only tangentially (as a manner of speech not as a geometrical operation) through the gray scale (fig.18).

Saying the same thing another way, the plane of value two contains a blue and a yellow but the blue is at full chroma while the yellow is a dark yellow, created by the admixture of black. High chroma yellow is on layer eight which also contains a blue but it is a light blue of greatly reduced chroma. Technically true blue on level two and vivid yellow on level eight cannot be related in the system according only to the variable of chroma. T. E. Cleland hints that they can in one of his superb drawings of the Munsell system for the Strathmore promotional book on color printing (Cleland,1931), but theoretically chroma relations hold only among colors at a specific layer (fig.19).

The psychophysical color space is also layered, although the layers are determined by brightness instead of value and, most importantly, the geometry of the color space is defined in such a way that the most saturated colors always occur on the plane of maximum lightness. This geometry creates a color space

that is approximately a three sided pyramid, with black at the apex and white, including the plane of maximum saturation, on base of the pyramid (figs.20,21). This geometry defines saturation as a relationship between hue, brightness, and the level of adaptation. The ideas I wish to establish about the psychological color space are (1) the plane of maximum saturation also contains a point of maximum brightness, and (2) the definition of saturation is "the chromatic response to the sum of the achromatic and chromatic responses." (Jameson and Hurvich, 1956:411)

I have devoted so much space to the descriptive definition of the vocabulary of color partially because an easy familiarity with brightness, hue and saturation is of critical importance for the following argument and partially to give a hint of the degree to which psychophysics depends on severing the connections between a perceiving organism and the objects of (color) perception. This is what I call the abstraction of sight and although I appreciate the rigorous distinctions psychophysics bases its color theory on; I think this rigor captures only half of the what constitutes seeing, the half best labeled "abstraction." The other half is "attraction" and the accident of a common root for these words allows me to postulate the conditions for a visual phenomenology. Following Kouwer's lead, I am as concerned with attraction as with abstraction, with potentiality as with actuality, with subjective phenomenon as with objective fact. Furthermore, I assume that there exist "way(s) of looking" and that all observers can introspectively re-con-

struct their practice of seeing in these different ways. I think of it as the "art of seeing" and happily Aldous Huxley (1894-1963) wrote a book about it by this same title.

The art of seeing

Huxley's purpose in The Art of Seeing (1942) is "to correlate the methods of visual education with the findings of modern psychology and critical philosophy" (p.10). The 'methods' to which Huxley is referring to are those of Dr. W.H. Bates who proposed a method of visual education intended to improve visual acuity without the use of spectacles. By 'modern psychology' Huxley means psychophysics, which he holds in the highest regard. In the end Huxley is concerned with correcting his own deficient vision. One is left with the impression that Huxley was so impressed with Bates' methods in his own struggle with blindness that he wanted to put Bates' ideas on a firm psychological and philosophical footing.

My purpose in "The art of seeing" is to explicate the conditions of maximum visual sensitiveness. Instead of treating the history of the physical basis of vision as a telos, a necessary development towards a greater abstraction; Aristotle is wrong, von Helmholtz is right (or visa versa), I seek to establish three presumptions. First, neither extreme condition is true; neither Aristotle's mediumistic participation of green in the eye with green in the object nor von Helmholtz' perfect abstraction of observed and observer. Secondly, I assume these extremes define a continuum on which the sensorium is able to locate it-

self, depending on the conditions of its level of receptivity. Thirdly, I assume humans can influence the sensitivity (objective criteria of the mechanism of vision) by the conditions of receptivity. It is obvious that Huxley's project and my assumptions do not exactly coincide; but they are deeply sympathetic and the schema Huxley uses to establish clear seeing I can use, with modifications, to establish maximum sensitiveness.

Huxley asserts that seeing equals sensing plus selecting plus perceiving. In a chapter of this title he inventories the components of seeing.

> Sensing is not the same as perceiving
> The eyes and nervous system do the sensing, the mind does the perceiving...
> Clear seeing is the product of accurate sensing and correct perceiving.
> Any improvement in the power of perceiving tends to be accompanied by an improvement in the power of sensing and of that product of sensing and perceiving which is seeing. (p.31)

Huxley agrees with von Helmholtz that sensing is not the same as perceiving but instead of subordinating sensation to perception he makes them partners in the act of seeing.

Huxley observes the components of the system include the eye, the mind and the nervous system and he asserts we can exercise a direct affect on the operation of the eye and of the mind, but that we can only indirectly affect the nervous system. He assumes there is a distinction to be drawn between spontaneous attention and cultivated attention and that by cultivating a habit of accurate sensing and correct perceiving we may see more clearly. Finally he thinks the relationship between perceiving

and sensing is reciprocal, sensing affects perceiving as much as perceiving affects sensing. Seeing is perception and sensation; interested and unattached; dynamic and relaxed. Below I will explain what these concepts imply.

To be interested and unattached is to cultivate acting as a spectator rather than expecting as an actor. Interest engages scenes consciously in vision and does not indulge in the kind of intellectual gluttony Huxley calls "ends gaining." "[S]ee a number of quite interesting but irrelevant things, which in real life could not struggle into our consciousness, bent as it would be, entirely upon the problems of our appropriate reaction" (Roger Fry in Huxley, 1982:139). Unattached implies an attitude of confidence and indifference. It is not detachment, which implies a turning away from, but unattachment which implies relaxed observation.

Huxley also proposes a way of seeing that he describes as 'dynamic relaxation'. He associates with dynamic relaxation with the normal and natural functioning of body and mind and he contrasts it to 'passive relaxation,' a state of complete repose.
Each state has its function in the process of visual re-education. Passive relaxation is a complete break in the activity of seeing. Using dynamic relaxation one learns "to combine relaxation with activity...to do what you have to do without strain; work hard, but never under tension" (p.24). According to Huxley the relaxation of psychological anxiety will alleviate physiological strains and promote easy movement. Motion is the crux of Dr. Bates' method. Huxley rightly notes that stabilized visual

fields disappear therefore, he concludes, freely shifting attention is critical to proper seeing. Mobility is to be cultivated in physical, mental and optical movements.

Good habits of seeing include "frequent and effortless blinking" (p.54). This prevents the eyes from fixating on one part of a scene and staring to the point of stabilization. As a practical matter one only stares to the point of blindness, in psychophysical experiments, but any prolonged fixation diminishes the acuity of sensation and therefore the accuracy of perception. Other movements all involve a combination of optical and mental facility and are called scanning, shifting and scaling.

Scanning allows freedom of eye movements laterally and vertically, promoting a dance of central fixations over the field of view. Fixation moves on before perception is fully conscious of what was seen. Shifting builds up an impression of a scene through a series of successive fixations aggregated into a composite sensory picture of which there is no single objective correlate. Scaling suggests that a different arrays of sensors may be engaged at different scales in different types of seeing.

Scanning, shifting and scaling are the cornerstone of an attractive way of seeing. The body is present and still, free from pangs of digestion, and reasonably comfortable. The eyes are scanning, gently probing the sky for a colored observation, appreciative of the beauty of a classic western sunset. The mind is free to associate, free to form questions. A shock forces gentle attention into willful appropriation, What was that flash? The reflective coating of a No Passing Zone sign.

From this experience I draw two tentative conclusions. There is more to seeing color than what the psychologists test for and there is more to seeing color than what the painters paint about. The artist cultivates a way of seeing that renders experience vividly and seeks to translate that experience into a language of feeling and form; if they are lucky creating an object that attracts.

The psychophysicist cultivates a way of seeing that isolates variables and reduces experience to experiment; if they are lucky creating an object the abstracts. Maybe the best of the artists are observational scientists of great rigor. Maybe the best of the scientists are moved by beauty and seek to render it in elegant formulae. But secretly I doubt it, though I am sure both, if asked, would pretend to the sensitivity of the other. This is the question that gnaws at me; why isn't our art more scientific and why isn't our science more artistic? It seems so simple.

If the question is about saturation why not study color under conditions in which it appears most vivid, at the gloaming or similar controlled conditions? Why try to construct a comprehensive color theory based on matching patches of a single solid color in the visual field. If one understands, hypothetically, the mechanism of simultaneous contrast and successive fixation, how can one possible generalize the study of light in isolated patches of specified angular subtense to the study of light in scenes of such great complexity that almost every possible condition of color is present? Turn these questions around on the

artist. Why not study the science of perception to learn how to better render a chosen view? If one understands, experientially, the unity of form and color, how is it possible to paint only abstractions? William D. Wright came to a similar set of questions at the end of his career. Claude Monet spent two decades painting his answer to the same questions.

Notes to Chapter Three

1. There is little danger that abstract in this context would be taken to mean "characterized by little or not reference to the appearance of objects in nature" but, just in case, I offer the following example. Given (1) a child's loose sketch of a particular scene, (2) a drawing made on a computer intended to be a realistic rendition of the same scene and (3) the scene itself, what would be the most abstract? According to the distinction I am concerned with the computer rendering would be more abstract than the child's sketch. No matter how non-representational was the sketch, the process of drawing it is closer to the person making it than the computer rendering, which interposes a mechanical prosthesis between the body and creation of the representation. Concerning the distance of the scene from the viewer, the scene both abstracts and attracts, confounding our attempts to say anything simply definitive about the relation of stimuli and stimulus, perceived and perceiver, object and subject. The question of representational "abstraction" is related to issues of perceptual mediation but I will not deal directly with the questions of "realism" here.

2. The question whether black, white and gray are colors is disputed. Generally writers with a scientific orientation say white is the presence of all colors, black is the absence of light and gray is a contrast effect--present in the observer but not physically present in the visual array. Writers in the context of art usually assume black, white and gray are colors since pigments exist that produce the impression of achromatic color (color without color, so to speak). Psychology is the field in which there is the most contention. Kouwer observes that the concepts black/white are not well differentiated from the concepts light/dark linguistically, and that this has led to 'most peculiar' confusions. In order to try to avoid these confusions I will use "grey" to refer to the impression of

'gray' and "gray" to refer to a pigment color. I will continue to use black and white somewhat ambiguously, meaning either the pigments or the impression of darkness or lightness; the precise meaning should be clear from the context. The important thing to remember is that the concept pairs black/white and dark/light are not equivalent. The significance of this lack of identity will be developed below.

3. The CIE is International Commission on Illumination an international body located in Vienna that legislates international standards on illumination, of which color standards are a part.

4. The OSA is the CIE's American counterpart.

5. An assumption of a "realist" position in the introduction absolves me from having to deal at length with Platonic idealism. I would simply like to note that Plato's epistemology is hostile to the project of the arts. Plato's expulsion of artists from his utopia at least indicates how seriously he took art, as his choice of a dramatic form for the presentation of his philosophical ideas show how good an artist he was.

6. It is not explained how the rays communicated the feel of the object back to the observer, but I imagine the process as very much like sonar. ("Sonar" is a neologism comprised of (so)und (na)vigation (r)anging.) For a contemporary evocation of the way sight might "feel" an object in view, see figure 3.

7. Specifically the implications which assert that 'knowing is a process unlike anything else' and that 'the mind is something which is aware only of representations and thus perhaps cut off from the world.' This is a paraphrase of two of the five problems of Cartesian dualism that Richard Rorty lists (1980:31).

8. According to Panofsky (1960), who references Lee (1967), who cites Panofsky (Renaissance scholarship is often just this way) Alberti borrowed the concepts "invention," "disposition," and "elocution" from a Ciceronian rhetorical tradition and transformed them into the categories of painterly tropes "circumspection," "composition" and "the reception of light." For another fine essay on the definition of late Renaissance artistic critical terminology see Alpers (1960).

8. I suspect that "cones" from "cones of light," is the root of our current name for the retinal sensors that function under scotopic lighting conditions. Most authors call attention to the shape of the nerve as a cone, wider at the sensing end, but this is only a convenient memory aid intended to help differentiate cones from rods, sensors active under photopic lighting conditions. In fact cones in the fovea centralis are not cone shaped, due to their close packing, and their actual shape varies depending on where they occur on the retina.

9. Oscar Kristeller argues:

> ...it has been my intention...to emphasize the additional fact, which is less widely known, that this Aristotelian tradition, though exposed to attacks and subject to transformations, continued strongly and vigorously to the end of the sixteenth century and even later. (1961:34)

In the case of color the 'even later' clause is certainly operative.

10. Richard Cytowic (1989) and Cytowic and Wood (1982) show that there is a sort of leakage among senses where affected persons might, for instance, "see" a color when they "hear" a sound; and by the work of S.S. Stevens, who shows how the reaction of a human subjects to a variety of sensory stimuli follows, in all cases, a power law.

11. A recent paper in Science I do not have a citation for because I herd about it on *All Things Considered*, reports that PET scans of blind people reading braille with the their finger tips lights up a part of the cortex associated with visual processing.

12. A fine apothegm by Lawrence Gowling in Sherman in Hall, 1987.

13. I shall use the variant spelling "grey" to refer to the impression of brightness and "gray" to refer to the impression of achromatic object color, but; ignore this distinction in quotes where the variant "grey" refers to British English.

14. Evans believes there are five dimensions of the perception of color, not three as does von Helmholtz, and that the opposite of greyness as a color is not dazzling brightness but fluorence (so named because of the tendency of bright colors to fluoresce). Fluorescence, in a strictly physical definition, is the ability of certain molecules to absorb energy from outside of the visible spectrum, specifically ultra violet rays, and emit that energy as visible light. Fluorescent colors like safety orange operate in this way and they display a perceptual component that does not easily reduce to a description according to hue, brightness and saturation. It is this component that Evans calls fluorence and, for him, it is the opposite of greyness.

15. This cursory treatment of complementary colors is, at this point incomplete, for in order to flesh it out we need the concept of a primary color. I will turn to a more complete discussion of color contrast below.

THE FALLACY OF PRIMACY

> *Here we come up against the bewildering duality of light as agent and object of vision. As agent it is a natural phenomenon, subject to the laws of physics; as object--belonging to pictorial content--it undergoes transformation into a visual language...Those writes who subject 'the language of art' to an analysis of the functioning of signs derived from a literary model tend to overlook this interaction. They overlook the fact that light mediates between the structures embodied in the pigmented surface and the processes of cognition. The duality of light as universal agent and potential object of vision cannot be paralleled in the linguistic model.* Paul Hills (1983:4)

The central questions of this chapter are "What is a primary color?" and "Why does it matter?" On the face of it this is a simple enough problem: define "primary," indicate the central role the definition plays, and get on with the argument. I do not think it is quite so simple, for two reasons. First, the entire history of color theory could be based on an exposition of what constitutes a primary color in each color system, color nomenclature, or color theory. The definition of "primary" is remarkably fluid, changing from system to system and changing within any given system as ideas about color evolve. The only constancy is in the idea of primacy itself.

Secondly, "primary colors" are where color as a linguistic phenomenon and color as a visual phenomenon overlap. It is enormously difficult to separate the visual from the linguistic, doubly so since I choose to do it in words. For the time being, suf-

fice it to say that the linguistic and the visual interpenetrate to a great degree; that vision is an important component of the linguistic construction of truth and that words are an important qualifier of the visual experience of seeing.

The definition of "primary" I shall adopt is: those colors from which all other colors in a given system may be created. This concept of Primary[1] is established in different systems using different names and linked to different colors. For Aristotle the genus, color is given by black and white. In Alberti singular genus becomes plural genera and the group of "true" colors are red, yellow, green and ashen. Newton called primary colors "homogeneous" lights. Von Helmholtz referred to primary colors as "principal" colors: red, green and violet.(Von Helmholtz' definition is at the root of the current notion there exist three colors the combination of which yields all colors.) Herring, a contemporary of von Helmholtz, called primary colors "unique" and argued that there are two pair of two colors: red/green and yellow/blue. Kenneth Low Kelly and Deane B. Judd identified ranges of colors that may be given "characteristic" names which act as de facto primary colors. In the following chapter I will offer a brief exposition of each of the systems and show how the linguistic assumption of primacy interferes with color perceived.

Aristotle's Primary Colors

Aristotle wrote several paragraphs on color in each of On the Soul, On Sense and Meteorologica and mentions color in passing throughout the body of his philosophical work. Aristotle's

ideas about color per se are fairly straightforward and as with other philosophers, the remarks on color are considerably complicated by their philosophical context in the corpus of his writings.

Aristotle's remarks on color in Meteorologica provide a sense of the phenomenological basis of his theory. Observing rainbows Aristotle seems to have noticed that the primary bow appears to divide the darkness of an exterior band from the lightness of an interior band. Since the colors of the rainbow grade from red on the bottom to purple[2] on the top he concludes that all colors are a mixture of lightness and darkness.

> [T]he Aristotelian theory was derived from the basic assumption, derived from Anaximenes, that light and darkness, or white and black, produce through mixture the other colors--from red, which contains more light than darkness, to blue (or purple), in which blackness predominates over whiteness...The multiplicity of colors is the result of differences in the proportions of the component parts. (Boyer, 1987:47)

Aristotle's meteorological observations support the idea that colors are produced from the mixture of light and dark and this basic attitude is consistent with what he argues in On Sense.

> Now, that which when present in air produces light may be present also in the translucent which pervades determinate bodies; or again it may not be present, but there may be a privation of it. Accordingly, as in the case of air, the one condition is light, the other darkness, in the same way that the colors white and black are generated in determinate bodies. (Aristotle in MacAdam, 1970:6. All further quotes from Aristotle in this chapter are in MacAdam.)

After linking light and dark in translucent bodies to white and black in "determinate" (opaque) bodies, Aristotle goes on to argue that the combination of white and black would "thus have the other colors for resultants" (p.6). He presents three ways black and white may combine to make up other colors; by juxtaposition, by superposition, and by interpenetration.

Juxtaposition places minute quantities of black and white so close together that "either separately would be invisible, though their combination would be visible; and that they could thus have the other colors for resultants" (p.6). Superposition is when "black and white appear one through the medium of the other, giving an effect like that sometimes produced by painters overlaying a less vivid upon a more vivid color..." (p.7) in what we would call a glaze. Interpenetration is a mixture of black and white "wholly blended together" so that we must "conceive those things to be mixed that are not diffusible into minima; it is in the case of these that natural mixture exhibits itself in its most perfect form." (p.8) Aristotle's basic proposal is that each of these instances of mixing color is the product of a ratio between two extremes, black and white (fig.22). If the ratios are composed of simple integers the color is regarded as "pleasing" otherwise the resulting color is "irregular."

Aristotle's idea that all colors scale between black and white is perfectly consistent with his metaphysics. As Samual Edgerton (1969) points out in an early scholarly analysis of color in Alberti, the idealization of Aristotle's color theory is his metaphysical system of oppositions.

> Since contraries admit of an intermediate...the intermediate must be composed of the contraries. For all intermediates are in the same genus as the things between which they stand...and in colours if we are to pass from white to black, we should come sooner to red and grey than to black. But to pass from one genus to another genus (i.e. from colour to figure) is not possible...intermediates, then, must be in the same genus as one another and as the things they stand between. (in Edgerton p.122 from *Metaphysics* parenthetical remark by S.E.)

Aristotle's metaphysics and his color theory, are predicated on the idea of a graded scale between dichotomous poles. In color the poles are black and white, lightness and darkness, and all other colors must be made to fit between these extremes. Therefore, Aristotle's primary colors are white and black and his concept of the mixing of colors allows white and black to coexist in colors (juxtapose), to lay over one another (superpose) and to mix to the extinction of their original identity (interpenetrate). Aristotle's ideas on color dominated natural philosophy for the next fifteen hundred years.

Alberti's Primary Colors

Natural philosophy at the time of the early Renaissance was still fundamentally Aristotelian. It was unacceptable to differ from Aristotle's orthodoxy, because his body of philosophical work had been absorbed into Christian (scholastic) doctrine. Yet, this is exactly what Leon Battista Alberti did in his radical theory of color.

Alberti is radical in two ways. First color had mostly been

written about in the "studio tradition" (by painters and to some degree alchemists) as a prescription. Vitruvius provides a typical example.

> It is now in place to describe the preparation of white lead and of verdigris, which with us is called "aeruca." In Rhodes they put shavings in jars, pour vinegar over them, and lay pieces of lead on the shavings; then they cover the jars with lids to prevent evaporation. After a definite time they open them, and find that the pieces of lead have become white. In the same way they put in plates of copper and make verdigris (Bk.vii,Chap.xii,Para.1; 1960:219)

Even though Alberti begs to be considered "as a painter writing of these things" (p.43) he does not take a prescriptive approach to color and the mixing of colors. He is not interested in how one manufactures vermilion. He is interested in how one harmonizes vermilion with verdigris, color with drawing, and finally with how color and form contribute to the theme of painting. In a word, Alberti wrote theory about the role of color in painting. This was a radically new idea, theorizing about art, and color played an important role.

Secondly Alberti, without flaunting his difference from Aristotle and using some of Aristotle's terminology, advances a rather profound idea about the mixing of color, one based upon a different conception of primary colors. The most important term Alberti and Aristotle share is "genus." For Aristotle the genius color was the linear continuity between white and black. For Alberti there is no genus of color. There are four genera of colors, established by analogy to the four elements (figs.23, 24).

> Through the mixing of colours infinite other colours are born, but there are only four true colors--as there are four elements--from which more and more other kinds of colours may be thus created. Red is the colour of fire, blue of air, green of water, and of the earth grey and ash.[3]
> (Alberti pp.49-50)

Alberti calls primary colors "true" colors (as translated by Spencer) and from these infinite other colors are born in two ways.

One way colors may be formed is by the combination of two (or more) true colors. There is nothing particularly profound about this observation, it is the stuff of preschool training in our own time and long practiced in the studio tradition. Possibly because Alberti's observation seems so obvious it is left unremarked upon in the literature, but it is not obvious. Rather I should say it is obvious to colorists that it is not through the mixing of true colors that "infinite other colors are born." In fact, it was obvious to Leonardo da Vinci that no two pigments could be mixed to make emerald green. It is obvious to young painters that mixing two chromatic pigments greatly dulls the resulting color, that more than three chromatic pigments in a mix yields mud, and that most really interesting colors cannot be mixed from true red, green, blue and yellow pigments. Finally it is obvious, from a strictly coloristic analysis of a vast range of oil painting, that most paintings are composed using a palette of colors restricted to a few chromatic pigments (usually not resembling true colors), white and black.

This last statement is a generalization with many outstand-

ing exceptions including the bodies of works by Titan (ca.1488-1576), Eugene Delacroix (1798-1863) and Oscar Kokoshka (1886-1980), although it is a generalization that accurately conveys one way painters use color. The point is that Alberti's "obvious" observation about mixing all colors from true colors is by no means unproblematic. It is not an effective strategy for colorists and yet it is, at base, the most popular misconception about the way pigments are mixed.

The other way "infinite colors are born" is by the mixing of white or black with any one of the true colors. This mixture forms what Alberti calls a "species" of color. Note how Aristotle's linear graded scale is considerably transformed by Alberti into a color space. Alberti's color space is not a fully articulated three dimensional space since as it has only four leaves in vertical section and one leaf in plan (fig.25); yet, the whole space (joining leaves through a common achromatic scale) is two orders of magnitude more complex than Aristotle's linear scale and therefore represents an early color "space."

Diagrammatic ruminations aside,
Alberti formulates a set of color relationships that have been absorbed into non-scientific culture as an intuitively obvious way to structure the relationships among colors. The primary colors are related to each other in a horizontal plane and related individually to black and white in four vertical leaves. The relationship among the leaves is determined by the variables they share; in elevation black and white and in horizontal section the true colors. But note: the position of colors not locat-

ed on axes is, at best uncertain and at worst indeterminable.

Newton's Primary Colors

In some ways Alberti's Enlightenment counterpart was Isaac Newton. Both participated in and helped define intellectual revolutions. Both wrote provocative color theories. Both composed their work in the shadow of Aristotle. There are other similarities but on this last point one may also formulate their greatest difference. Where Alberti gently disagreed with Aristotle, Newton forever changed the nature of natural philosophy, exposing Aristotelian dogma as the mixture of acute observation and unfounded inference. One way to examine this change is to consider Newton's concept of a primary color.

Newton's statements on primary colors are somewhat contradictory. There are colors in his optics that are used to make up other colors (the definition of "primary color" given above) and there are colors that Newton calls "primary." The colors that Newton calls primary are the colors of the spectrum: red, orange, yellow, green, blue, indigo,[4] and violet, but it was an entirely arbitrary decision on Newton's part to call these colors primary. Initially Newton named five colors in the spectrum, later he changed that number to seven. He changed his mind by simply asserting there was a correspondence between the seven notes of the diatonic scale and the colors of the spectrum (fig.26):

> And possibly colour may be distinguished into its principall Degrees, Red, Orange, Yellow, Green, Blue, Indigo and deep

> Violet, on the same ground, that Sound within an eighth [octave] is graduated into tones. (Newton in Hall, 1993:76, from the letters)

Newton's theory of color, as opposed to his theory of harmonic proportion, implies an infinite number of primary colors. As Richard Westfall observes: "The argument of two millenia's standing as to the number of primary colors was terminated with the unexpected answer of infinity" (p.357). Newton used the word "homogenous" to describe this kind of primary color, colors that when combined make all other colors but most notably white.

Newton's concept of homogenous light is at the heart of his new understanding of colors. A. Rupert Hall notes that what Newton's theory of color (as completed by the summer of 1668) may be summarized in three statements:

> 1. A pure coloured ray of light is homogeneous and elemental. 2. To each pure colour belongs a specific degree of refrangibility. 3. White light is a mixture of such rays. (1) is a basic theoretical proposition. (2) is the basis of the mathematical theory of colour, and Newton attached immense importance to it. (3) is a basic proposition about the natural world, essential to any physical theory of the nature of light. (Hall, 1993:41)

The concept of homogeneous light is central to the first two propositions because this kind of light is alternately elemental and pure. It is elemental because homogenous light cannot be decomposed any further. It is pure because the ratios of refrangibility are invariant and therefore expressible mathemat-

ically. The concept of homogeneous light is central to the third proposition, as it is central to the Opticks in general.

Homogenous lights combine to make up white light and all other heterogeneous colors. All colors of light (except white) may be homogeneous or heterogeneous and only inspection of the light with the aid of a prism will tell if the color is simple or compound, primary or mixed.

> For a Mixture of homogeneal red and yellow compounds an Orange, like in appearance of Colour to the orange which in the series of unmixed prismatick Colours lies between them; but the Light of one orange is homogeneal as to Refrangibility, and that of the other is heterogeneal, and the Colour of the one, if viewed through a Prism, remains unchanged, that of the other is changed and resolved into its component Colours red and yellow. (Newton p.132)

Newton's ingenious experiments, as reported in Book I, repeatedly illustrate the decomposition of white light into homogeneous colored lights. These experiments are part of what make his theory a physical theory and not just a mathematical abstraction. They show how close Newton stayed to the phenomenological observation of light and color.

It is important to introduce one qualification and one observation to Newton's ideas. The qualification pertains to the number of homogeneous lights. There are an infinite number of homogeneous lights in a mathematical theory where the continuum of an energy distribution can, theoretically, be infinitely subdivided. But from a perceptual point of view the continuum is not infinitely divisible. There is a point beyond which humans cannot distinguish between neighboring homogeneous colors. This thres-

hold is called a just noticeable difference (jnd) and although it varies slightly for different color normal observers, there is, functionally, a "grain" beyond which the sensorium cannot go. Ralph Evans makes just this point in An Introduction to Color:

> The statement that there are an infinite number [of colored lights] involves the assumption of infinitesimal differences between them. If the differences are assumed to be discriminative, the number becomes finite and not very large. (Evans P.235)

When one defines primary colors as homogenous lights the number of primary colors expands greatly from Alberti's four to a number around two hundred (the number of discriminable colors there are in a hue circle, see Chapanis, 1965 and Nickerson and Newhall, 1943.

An observation on Newton's ideas about primary color pertains to the color circle, first sketched in the Optical Lectures (1670-72) and later published in the Opticks as Fig.11, Part II, Book One (p.155) (figs.26,27,28).

> The point of the colour-circle was that it enabled Newton to fix intensity as well as hue. The circumference of the circle is coloured exactly like a spectrum bent around on itself; the center of gravity of each band or arc of colour is noted. (Hall, 1993:115)

This color circle is the antecedent of the 1931 Spectrum Locus and it is important to note that, by definition, the colors located on the perimeter of the circle are 'uncompounded' or homogeneous. Newton's concept of what Hall calls "intensity" involved mixing white light with homogeneous colored light which diminished the purity of the color of the homogeneous light but

did not alter its color.

> So if to the Colour of any homogeneal Light, the Sun's white Light composed of all sorts of Rays be added, that Colour will not vanish or change its Species, but be diluted... (Newton, 1952:133)

The dilution of 'homogeneal' light alters the quantity color in the light, which is distinct from the compounding of different homogeneous lights that alter the quality of colored light. A qualitatively different colored light, one created from compound lights cannot be located on the perimeter of the color circle since it is not homogeneous.

Qualifications and extensions aside, Newton re-invented mathematical optics; founded on his discovery of the heterogeneity of white light, that nature of homogeneous light and the weighting of compound lights. Newton's work, further qualified by Hermann von Helmholtz, would become the foundation for a rigorous psychology of color.

Von Helmholtz, Hering and Primary Colors

The concept of Primary[5] that surfaces in Hermann von Helmholtz takes off from Newton's color circle.

> The primary colours of the spectrum are arranged in a series around the circumference of a circle, beginning with red, and by imperceptible degrees[[6]] passing through the various hues of the rainbow to violet. The red and violet are united by shades of purple, which on the one side pass off to the indigo and blue tints, and on the other through crimson and scarlet to orange. (Von Helmholtz p.127)

Von Helmholtz is qualifying Newton in this passage by enlarging

Newton's color circle to include colors that are not part of the spectrum of sunlight. Where in Newton's color circle violet, the most refrangible ray, butts up against red, the least refrangible ray; in von Helmholtz's circle purple has been interposed between them (fig.29). The range of purple lights (and by extension purple object colors) do not occur in the spectrum of white light and therefore are referred to as non-spectral colors (fig.30). This does not mean that von Helmholtz thought of purple as another primary color, just that he found it necessary to modify Newton's basic concept of the color circle in order to add a whole class of colors left unaccounted for in Newton's foundational theories. Of course, if Newton had included the purples in his circle, those that fell on the perimeter would have been, by definition, homogeneous (and therefore primary). But von Helmholtz is not required to include purple in his list of primary colors, because he defines primary differently.

Von Helmholtz finds the colors of the spectrum that are most saturated:

> will not arrange themselves in the form of a circle. The circumference of the diagram presents three projections corresponding to the red, the green, and the violet, so that the colour circle is more properly a triangle, with the corners rounded off... (von Helmholtz p.128)

The differences between Newton and von Helmholtz on this point are, on the one hand, a matter of differently drawn diagrams, trifles, and on the other hand, of critical importance. Newton's assumption is that all homogeneous colors are undiluted by white light and therefore are equally distant from the center (white)

point of the color circle. Von Helmholtz, building on the work of Thomas Young (1773-1829) and James Clerk Maxwell (1831-1879) assumes that they are not. This assumption is of critical importance for von Helmholtz because it allows him to privilege what he imagines to be the three most saturated colors and derive all other colors from these three, thereby reviving the idea that there are a finite and very small number of primary colors. Three, to be exact: red, green and violet.

It was von Helmholtz' rediscovery of Young's almost forgotten work of the early nineteenth century, that allowed von Helmholtz to reformulate Newton's physical theory as a psychophysical theory, largely through the reintroduction of the idea of primary colors:

> ...as it is almost impossible to conceive each sensitive point on the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it becomes necessary to suppose the number limited, for instance to the three principal colours, red, yellow, and blue...and each sensitive filament of the nerve may consist of three portions, one for each principal colour. (Young, 1802:21)

Note the shift from physical properties to psychological properties of color. The primary colors are not characteristic of light or of color but characteristic of the sensing mechanism in the retina. In other words, in what became known as the Young-Helmholtz theory of vision, the innate color sensitivities of three sensing mechanisms become primary colors. Von Helmholtz did not know what the precise tint of these colors were and his substitution of red, green and violet for Young's red, yellow and

blue was informed conjecture, but the reintroduction of the assumption of Primary was secure. Von Helmholtz even italicized the point: "all differences of hue depend upon combinations in different proportions of the three primary colors" (p.130). He justified his theory on the basis of its economy.

> The system of naturally visible colours offers us a series of varieties in the composition of light, but the number of those varieties is wonderfully reduced from an unlimited number to only three. (Von Helmholtz, 1962:139)

Von Helmholtz, with Young shifts the study of color from the study of the wave properties of light, the spectrum, to the study of visual sensing mechanisms, the eye. In the process he (1) revives Young's hypothesis of a three component sensing mechanism and (2) postulates that all colors can be mixed by the combination of three primary colors, which is why it is called the trichromatic theory.

Von Helmholtz' influence in color theory was quite decisive. As A.C. Crombie (1958) notes not only was von Helmholtz a physician, a gifted experimental researcher in vision and in acoustics, an epistemic philosopher partially responsible for a new scientific orientation in German philosophy, and a mathematician. He also formulated a fundamental physical law: the conservation of energy. With such a formidable fellow it must have been difficult to start an argument. Yet, metaphorically speaking, this is exactly what Ewald Hering attempted.

Hering, approached the problem of color from a phenomenological point of view. He pointed out some effects for which the trichromatic theory could not account. "For instance" (drawing

from Color for Philosophers, 1993)

> purple seems to have both reddish and bluish constituents in it, and is readily describable as a reddish blue or a bluish red. It could thus plausibly be the result of mixing "red" cone outputs with "blue" cone outputs, by analogy with the mixture of "red" light and "blue" light to give "purple" light. But yellow, which is generated by mixing "red" light with "green" light, does not seem to be a reddish green or a greenish red. Indeed, there are no reddish greens. On the (then) accepted model, how could one account for the perceptually unitary character of yellow and the perceptually composite character of purple? (Hardin, 1993:29)

As the consequence of his critique of von Helmholtz, Hering formed his theory of the sensing mechanism for color based on opposing pairs of "unique" colors (a "primary" color by another name is still primary). The opposing sensations, he said, are white/ black, red/green and yellow/blue. Unique (or sometimes "unitary") colors are four in number and each color has no resemblance to any of the other three (Burnham, 1963:3.1.2a.2; fig.31). In other words unique red is a red that does not appear to be tinged with either yellow or blue. Unique blue is a blue that displays no red or green. Unique green exhibits no blue or yellow, likewise unique yellow is not colored by red or green.

Hering's "opponent color" challenge of trichromatic theory was eclipsed by von Helmholtz' authority until Hurvich and Jameson revived opponent color theory in the mid 1950's. They have refined Hering's concepts into a color theory for the specification of a psychological color system today called the Hue, Brightness, and Saturation (HBS) system and, in the process,

enriched the definition of unique colors (fig.32).

Another way to define unique colors is as those colors that do not shift in hue with differences in brightness. This shift is also known as the Bezold-Brucke effect.

> Specifically, colors of spectral lights that appear red yellow (orange) or green yellow at moderate intensities appear yellower at higher intensities, and wavelengths that appear red blue (purple) or green blue at moderate intensities appear bluer when the luminance level is increased. (Agoston, 1975:183)

Yellow, red, green, and blue are not altered by an increase or decrease of brightness, in the perception of hue, and are thus unique colors, Primary according to opponent theory

A final note on the relationship between the von Helmholtz' trichromatic color processing and Hering's opponent color processing theory. Nowadays it is generally accepted that they represent two different stages in the processing of color signals (even though the exact mathematical model for the transformation from retinal trichromatic processing to post retinal opponent processing is still debated, see fig.33). The argument for different processing mechanisms taking place at different stages, like the argument for trichromatic processing above, is also fundamentally "economic". Hardin says it best.

> [T]he retinal image is sampled by more than 120 million receptors, of which 7 million are foveal cones. Yet all of that information must be transmitted over an optic nerve that contains only 1.2 million fibers. Part of the required transmission economy is achieved by letting the achromatic system handle fine resolution...The other part can be

> achieved by exploiting the redundancy inherent in the considerable overlap of the absorption spectra of the cones. Because of this, the only chromatic information that needs to be transported are the differences of the cone outputs, a far more economical alternative than transmitting the output for each cone type separately. (Hardin, 1988:33)

In conclusion, even though the processing of three primary colors and four unitary or unique colors are now assumed to be compatible, it remains a cornerstone of the theory of color vision that there are only a few basic responses to color and that all colors are determined by the combination of a small number of responses to primary colors. Not surprisingly there is also a color vocabulary that reflects. A scientific (psychophysical) model of color.

Scientific Color Naming

The theory of color language exists more in philosophical and anthropological traditions (where there is a very clear definition of what constitutes a primary color[7]) than in the natural philosophical tradition, where there is no serious attempt to define what constitutes a primary color in linguistic terms. Yet, the ISCC-NBS (Inter-Society Colour Council / National Bureau of Standards) have agreed on a list of 267 color terms that attempts to standardize color naming. Mapping a vocabulary of color terms, compounded and modified in a systematic way, onto a color order system one is actually restricting the communicative potential of color names. I suspect that Kelly and Judd, compilers of the thesaurus that matches names such as "turquoise" to the less ambiguous descriptions such as "strong bluish green," would not dis-

agree. The purpose of a standardized scientific vocabulary of colors is to diminish the ambiguity attached to color names by creating a system for discussing colors in a fairly specific way, without having to refer to particular physical color samples.

The 267 color terms of the ISCC-NBS vocabulary are grouped in twenty-six species of colors that are given simple and compound characteristic names (fig.34). As in Alberti's color space, where the leaves red, green, blue, and yellow share a common scale of black and white, the species of colors in the ISCC-NBS color vocabulary share a scale of neutral (achromatic) colors. The simple species names are: pink, red, orange, brown, yellow, olive, green, blue, violet, and purple. The compound species names are yellowish pink, reddish orange, reddish brown, orange yellow, yellowish brown, olive brown, greenish yellow, yellow green, olive green, yellowish green, bluish green, greenish blue, purplish blue, reddish purple, purplish pink and purplish red.

Think of each species as identifying a vertical leaf of a color solid. Each leaf is further subdivided, according to the color of the particular leaf by additional modifiers. The modifiers follow a consistent pattern. Using purple as an example, the first column moving out from the grey scale (from top to bottom) would be purplish white, light purplish gray, purplish gray, dark purplish gray, and purplish black. The next column out would be very pale purple, pale purple, grayish purple, dark purple, and very dark purple. The next column is very light purple, light purple, purple. Modifiers in the next column are brilliant, strong, deep, and very deep. Finally, at maximum saturation for

any given color leaf, the species name is modified by vivid (figs.35,36).

What is interesting in this arrangement is the status of the un-compounded species names--pink, red, orange, brown, yellow, olive, green, blue, violet, and purple--as de facto "primary" colors. Compounded and modified, these ten names make up the whole system. It is a system somewhat more complicated than an opponent color system with only four unique colors. It is even more complicated than Newton's seven spectral color system. But the system still assumes that the entire range of color experience can be reduced to a finite and relatively small number of unique colors that, properly modified, can account for most color phenomena. This is precisely the conceit I wish to dispel.

Primary Colors in Review

I have told the story of the history of the idea of primary colors because it is important to show the thematic links between different thinkers at different times. To summarize these ideas in a somewhat schematic way: there are, in the general history, at least three traditions--a studio tradition, a natural philosophical tradition, and a linguistic tradition. I have by no means treated these traditions exhaustively but one may draw some useful generalizations. The studio tradition, represented by Alberti, is concerned with mixing pigments. This is the most literally materialistic tradition, concerned with substances and how to mix them. Alberti went somewhat against the grain by writing theoretically about color, color space and color harmony, but he

is still representative of the studio tradition. In this tradition a primary color is a "true color" and and a theory of color is to be constructed from the materials with which one has to work--pigments.

The scientific tradition, in Newton's discovery that colorless light is heterogeneous, has concerned itself with the composition of light and in von Helmholtz, with psychophysics of vision. The psychophysical model is more complex than the studio model, because the scientific model includes the color of illumination and the sensitivities of the perceiving mechanism in a single theory. The older studio model is not sophisticated in this way.

The scientific model also includes, as part of its account of color, the observer. This was the whole point of the reintroduction of primary colors by von Helmholtz. The observer is placed at the center of the sensation of color. Never mind that the observer is a fiction based on statistics that vary widely in the finest grain of color perception, she is there.

Including the observer in the model of color perception was a stroke of genius and raised a deeply disturbing problem. It was brilliant because it complexified the color model one more step. It was, and remains, disturbing because as the spectrum became the spectrum locus, founded on the distribution sensitivity of cones, a contradiction arises. The perimeter of the spectrum locus represents homogeneous colors, colors not composed by a mixture of components; but, the spectrum locus is formed according to the mixtures of three primary colors. Colorimeterists do

not see this as a contradiction because three homogeneous lights act as a limiting case of color sensa derived from the combination of three retinal sensors. Yet, even von Helmholtz recognized that there are color perceptions that exist beyond the boundary of the spectrum locus.

In other words the perimeter of the spectrum locus represents a limiting case of color sensation but not of color perception. I suspect this boundary is not as clearly fixed, or as well behaved, as the model suggests and, that in the space between what is reproducible (sensation) and what is visible (perception), very interesting phenomena transpire. Phenomena such as vividness, which may not be predictable according to the same rules that function within the limits of the spectrum locus.

Within the scientific tradition as we have seen "primary" may mean any of a handful of things. It may mean homogeneous which is un-compound light. It may mean "principal" in von Helmholtz' sense, i.e. determined by the trichromatic mechanism of the eye doing the sensing. It may mean "unique" in the sense of HBS opponent processing. Finally "primary" may mean "characteristic" as it does in the vocabulary developed by Kelly and Judd.

What is interesting is that in both the scientific tradition and the studio tradition, the result of mixing colors, lights or pigments, is assumed to be be predictable, testable from theory. And it is to various degrees. Add true yellow to true blue pigment and one gets green. Add black to red and one gets darker red. Add white to green and one gets lighter green. A lighter

green models up from true green, a darker red models down from true red. Within these general parameters, color pigment mixing is predictable in the studio tradition. The psychophysical model provides a more precise prediction of something closely related. Given an objectively verifiable wavelength of light what color will an observer with normal color vision see? Or, in a slightly more complicated situation: given the spectral distribution of illumination, the spectral absorption characteristic of the surface and the spectral sensitivity of the mechanism of observation (the eye/"lower" brain combination) what color will be perceived? This is called the question of "color appearance", and although it is no longer at the center of visual science, it is still considered important.

The answer to the question is surprisingly restricted. Judd (1962:32) indicates just how restricted. Assuming normal color vision and structure free patches of color (1) of the same size, (2) of the same shape, and (3) of known spectral radiances. Then, and only then, we can predict whether two colors will look alike. Notice how this rigorous definition excludes the scenes most people would encounter during a walk in the park, with its rich textures, shadows, and lighting conditions, or working at a computer with its luminescent phosphorus. Scientists can only generally predict color perception from color stimulus analogous to the way artists can only generally predict the color result of mixing pigments. Therefore, in both the studio and the scientific traditions the question of primacy becomes mainly an operational assumption--the trade off one makes among competing requirements.

How does one match a restricted set of mixing colors to an optimum set of colors mixed within available technology? In this context the distinction between primary and not primary colors is a pragmatic one that really only makes sense in a specific technological context. In the context of color printing it is often remarked that printers only use one color of red "process magenta" to mix all of the colors of red that occur in, for instance, paintings (fig.37). The assumption on the part of color printers is that process colors mixed and printed on a bright, white, clay-coated paper, will get you close enough to the "encaustic maroon" of a Mark Rothko painting. If one needs a more accurate experience of color, go and see the painting.

In many colorimetric experiments three lights of a single dominant wavelength are adjusted for intensity and used to match target colors. According to theory any three colored lights will do as long as one of the lights is not derivable from any of the other two. As a practical matter however, violet, green and red lights are almost always used because human subjects can match the largest gamut of colors using these colored lights (fig.38).

The definition of an operational approach is where the parameters of the solution are given by the constraints of the technology. If this argument is correct, it seems that technology is driving theory, which determines the experimental set up, which "confirms" the theory. But it does not makes sense to allow an operational model to determine the means by which we formulate a theory which aspires to model color phenomena.

Given that the studio model and the scientific model of

color are related by different but analogous prejudices--prejudices built into their respective ideas of what constitutes a primary color--the true constancy of studio and scientific models is the idea of primacy itself. In every case, possibly excepting Newton's homogeneous colors, it is asserted that a small number of colors are constitutive of all seeable colors, and then a new theory is constructed upon the unproven assertion.

Aristotle constructed the theory of the rainbow on the basis of the contrast between black and white. Alberti constructed a theory of color based on how the pigments available to him mix to make colors. Newton constructed a physical theory based on the harmonic combination of the seven spectral colors he distinguish from "white" light. Von Helmholtz created a trichromatic theory based on unequal saturation among colors. Hering advanced an opponent processing of color sensations to explain phenomena von Helmholtz could not. Kelly and Judd pare down color vocabulary to it smallest possible set of characteristic terms and then theorize it is the most efficient way to name/identify particular colors. All of these theories assume a small number of primary colors.

The Fallacy of Primacy

Since the idea of Primacy is the most obvious characteristic these theories share one might attack it using a deconstructivist method. Establish that the intellectual history of the West is founded on dichotomies as in this quote St. Augustine.

The so-called antitheses are indeed the most beautiful of

> the embellishments of speech...And just as such a confrontation of opposites makes the beauty of the style, so the beauty of the universe is fashioned through confrontations of opposites, in a style which does not deal in words but in things...And so should you consider the works of the Almighty in pairs, the one confronting the other"
> (in De civitate Dei:11.19; in Kemp, 1991:108).

Then argue that the "metaphysics of presence" is founded on the "privileging" of one of the poles of the dichotomy. In the case of color--already deemed a secondary quality by natural philosophers--show that the distinction between primary and secondary qualities gets transferred to color as a distinction between colors that make up other colors and the colors that get made up.

Deconstruct the notion of primary colors by showing how the colors mixed are more primary than the "primaries." Reverse the priority of primary and secondary qualities in natural philosophy (thereby "marking" secondary qualities) and arrive through clever word play at the substitution of color for location as a primary quality. Finally, undo the Cartesian mind / body dualism by showing how color proves that the boundary between the mind and the body is too fluid to be rendered in anything so crude as the "privileged" (or even the "marked") term of a linguistic dichotomy.

Challenging linguistic dichotomy (as a method) is not, however, a deconstructivist trope. It is more akin to the strategy in Gadamer's Philosophical Hermeneutics.

> My thesis is...that the thing which hermeneutics teaches us is to see through the dogmatism of asserting an opposition and separation between the ongoing, natural "tradition" and the reflective appropriation of it.

(Gadamer, 1976:28)

Temperate as Gadamer's thesis is, when compared with deconstruction it is still a form of psychological nominalism "the doctrine that all awareness is a linguistic affair" (Rorty, 1982:99). As Gadamer says it:

> The phenomenon of understanding, then, shows the universality of human linguisticality as a limitless medium that carries everything within it--not only the "culture" that has been handed down to us through language, but absolutely everything--because everything (in the world and out of it) is included in "understandings" and understanding [is that] in which we move. (Gadamer, 1976:28)

I would move outside of critical theory and finally outside of the radical relativism of post structuralism as well. Color can engage us apart from language and whereas anything I would say about this engagement brings experience back to discourse I agree with Susan K. Langer that:

> Whatever resists projection into the discursive form of language is, indeed, hard to hold in conception, and perhaps impossible to communicate, in the proper and strict sense of the word "communicate." But fortunately our logical intuition...is really much more powerful than we commonly believe, and our knowledge...is considerably wider than our discourse. (Langer, 1957:23)

The point is that the perception of color exists on its own terms, compelling aplenty when one gives up sanctioned apperception for acute observation.

Acute observation is the visual interrogation of a scene with the intent of allowing sensation to guide perception. Remembering that sensation and perception are artificial distinc-

tions used to allow one to discuss constituent parts of the visual process, I would like to revive a concept used to describe another (hypothetical) distinction relevant to the relationship between color and language.

The concept is "apperception" which is located in the fictitious space between sensing and perceiving. Since it is a philosophical word almost no longer in use, I shall offer a dictionary definition.

> Apperception is distinguished from perception as being the internal act, or rather reaction, by which the mind adjusts the objects present in perception to its knowledge already stored up in experience. "In perception we have an object presented to our senses, but in apperception we identify the object or those features of it which are familiar to us before we recognize it, explain it, or interpret the new by our previous knowledge. We classify it under various general classes." (W2, at apperception, quote from Leibnitz)

Visual apperception is the preliminary mapping of sense data onto schematic visual observation--as a test for the worthiness of direct attention. It is the categorization of sensation prior to perception. It is a quasi-linguistic intervening step between the monitoring of the visual world and the recognition of an object worthy of attention.

Categories of colors, primary color names, are a preliminary test for detailed inspection in apperception. If one is hungry and the desired food is strawberries, red is categorized as worthy of detailed attention. If danger is tan. Then all yellow brown objects (and more importantly moving yellow brown objects) will be categorized as dangerous and worthy of immediate atten-

tion. In both examples, perception, which is a most sophisticated integration of numerous sensations, is directed by a first approximation of the fit between sensa and the category of color that fits objects of desire (or dread).

However, the act of monitoring the visual world for clues can also foster a vicious circle in the form of a self-fulfilling prophecy--particularly since humans rarely scan the world exclusively for color clues. Instead of interrogating a visual world for the subtle coloristic information it contains, we tend to identify colors according to a color vocabulary founded on gross distinctions. We generally ignore the information, for example, that one certain wall is one certain green and simply register it as "green." Ignoring the particularity of colors, we become habituated to apperceiving them in terms of classes of colors and thinking of all colors in terms of their generic name. This is precisely why the ICCS-NBS color terminology is so dangerous. It supports the migration of a particular color experience towards a generic color recognition.

Take as an example the description of the west Kansas landscape facing away from the sun.

> I remember the colors (remembering color memory often plays tricks) as DARK GREEN and...apple-green, willow-green, swallow-gray, sauce brown, sky-blue, peach-pink, jade, lotus stem, silver green, fish-belly-white, ink wash, pebble-blue, reed-flower, litche, coral color, and duck's-head green.[8]

Now convert this passage into a psychophysical vocabulary:

> I remember the colors as DARK GREEN and...yellowish green, yellowish green, dark grayish green, dark grayish yellowish brown, deep blue (etcetera), strong yellowish pink, light

bluish green, moderate green, light greenish gray, light gray, gray, dark bluish gray, (etcetera) and brilliant green.

Is this the best way to attribute colors to objects given that one's intention is a sensitive observation of color? I think not. Therefore, is the only way to study vivid color to short circuit apperception and treat all colors as primary colors? Maybe, but this alternative renders all experiences of color as local to a particular time and place. It is perhaps unreasonable to believe we can reform our apperceptual mechanism in this way on a permanent basis, but here is a test: the next time you notice a scene in which the colors are particularly beautiful, try looking in such as way as to treat all object colors as unique and all shadows as colored. You might see colors much richer in variety than the vocabulary of color permits and very much richer than the primary colors and their admixtures can plot in any color space.

Scientific Color Naming II

Even though the rich vocabulary of color words such as turquoise, scarlet, periwinkle, etcetera is preferable to the "scientific" color vocabulary for literary purposes, the ICCS-NBS terminology does not properly present the descriptive potential of scientific color terminology. To get a sense of the scope of the scientific description of color one must consider a different class of scientific words. These words represent a large body of experimental evidence which grounds, and is grounded, by princi-

ples, connected through inferential chains to propositions, warranted by experiments, in a hermeneutic circle. It is difficult, for example, to invoke the construct called the CIE Chromaticity Diagram without tracing some of the inferential chains of experiment and experience upon which it is constructed. Therefore, I have split the discussion of the terminology of visual color science between Chapter Three and Chapter Four of this thesis, to give the reader a chance to absorb the concepts of brightness, hue and saturation as attributes of sensation before introducing luminance, dominant wavelength, purity and chromaticity as the psychophysical correlates of sensation based on the chromaticity diagram.

Von Helmholtz' differentiates between physics and psychology. Psychology is further differentiated into sensation and perception. Perception aggregates the attributes of sensation into modes. The psychophysical modes of appearance are divided between luminant modes and object modes. Luminant modes collect distinct sensations into aggregate perceptions related to the behavior of light. In other words, brightness, hue and saturation combine to form the illumination mode of appearance (fig.40). A complete list of the attributes of sensation, as identified by the committee on colorimetry of the OSA (1946) includes brightness, hue, saturation, (discussed in detail in Chapter Three), size, shape, location, flicker, sparkle, transparency, glossiness and luster. I will not offer a detailed discussion of all of the attributes of sensation, I remark on them here only to draw the distinction between illumination and surface modes of appearance.

The "surface" mode of appearance includes all eleven attributes, the illumination mode only three. Color psychophysics is overwhelmingly concerned with with the illumination mode of appearance. Even when psychophysical model is used to describe the color of objects (by definition an object mode of perception) the size, shape, location, flicker, sparkle, transparency, glossiness and luster of objects are simply controlled so they are no longer variable.

Since color in visual science is defined only in terms of brightness hue and saturation in the illumination mode of appearance, I must define the psychophysical correlates of brightness, hue and saturation in order to be able to present the limitations and insights of color science. Brightness correlates to luminosity, hue to dominant wavelength and saturation to purity (and to a lesser degree chromaticity). What follows are the discursive definitions of luminosity, dominant wavelength, purity and chromaticity, but first I must discuss why the science of color is called "additive."

The basic distinction between additive and subtractive color mixing is related to the distinction between incident and reflected light (figs.37,38). One is tempted, as a consequence, to define additive color as the spectral composition of incident light and subtractive color as the spectral composition of reflected light (from pigments or materials). Though there is some truth in this casual definition, it is subtly misleading.

Everybody who has ever read about color knows that the scientific study of color is concerned with additive interact-

ions. The reason for this is simple. The radiant energies of incident light are simply summable over a given range of frequencies. Technically this summing is an integration of the area under the curve of a graph of energy (measured in watts per micron) by wavelength (measured in millimicrons "mu" or in nanometers "nm") within the range of human sensitivity (approximately 400-700mu)(fig.59). Real colors do not follow algebraic formulas, yet this operation may be graphically described.

This much of the physics of light is implicit in Newton and, indeed, if the perception of color behaved in the same way a simple summing operation would add the absorption characteristics of the surface being irradiated to the the spectral composition of the radiating energy to arrive at a reliable prediction of the color perceived in the reflected light. But very few bodies absorb extra energy equally over all wavelengths. In this situation one must sum the spectral composition of incident light and the absorption rates at different wavelengths of the surface to arrive at a spectral distribution of the reflected radiant energy (fig.41).

There is, at this point, still no color per se in the radiant energy since the selective sensitivity of the eye has not been summed with the spectral distribution of the reflecting surface. But, having summed the composition of incident light with the absorption characteristics of the reflecting surface, one may at least postulate the spectral distribution of ideal colors (fig.42) Most bodies, however, do not interact linearly with incident light and this group of absorption phenomena are

bracketed off from physical theory and called subtractive color. Instances of subtractive phenomena must be measured on a case by case basis.

Luminosity is the psychophysical correlate of brightness and is the quantification of incident energy (defined discursively in Chapter Five) upon the eye or the retina. Luminous flux is radiant flux (a wavelength by wavelength summation of the spectral composition of the light source) summed with the relative sensitivity of the human eye. The summation of source wavelength and sensitivity wavelength is not a precise quantity because different people respond to the same light(s) with slightly different sensitivity curves (fig.43). As a consequence, the range of sensitivity of the eye is defined by a statistical average among a group of color-normal subjects in response to a common source illuminant. This average, called the "standard observer", is the bridge between physics and psychophysics since the averaged response curves allow for the mathematical treatment of sensation.

Luminosity, therefore, sums three phenomena. The spectral composition of a light source, the efficiency of reflectance (or transmittance) of light, and the spectral sensitivity of a standard eye. Wavelength is the term common to each of these measurements and is the basis for constructing the response of the eye to luminous flux[9]. The important thing to remember is that luminosity provides a measure of how a "standard" eye will decode a light source / object interaction but not how the color will be sensed. Therefore, luminosity is a psychophysical analogue to brightness which, because it is not rigorously

defined, is considered an attribute of sensation while luminosity is a mathematical model of an interaction between the physics of light and the physiology of the human eye.

Luminosity is the color without color, so to speak,the light context in which we judge objects and their attributes such as size, color, shape, location, etc. When we evaluate luminosity we tend to evaluate primarily the overall quantity of illumination and secondarily the spectral distribution of the quality of illumination issuing from a particular part of the visual world. The different qualities of illumination are measurable as different color temperatures (figs.45,46) but the perception of white objects illuminated by different color temperatures tends towards some "white" psychological norm. The eye senses color temperature accurately but perception equalizes white objects under the chromatic distribution of, for instance, fluorescent light and sunlight.

This phenomena is known as brightness constancy, and is the tendency of perceptual objects to retain their normal appearance regardless of local lighting conditions. Given some time to adapt to different color temperatures of illumination, a white piece of paper looks equally white in both sunlight and in shade, day and night, under incandescent or fluorescent light. If there was no brightness color constancy phenomenon, white paper illuminated by fluorescent light would look bluish.

The psychological mechanism that provides us with brightness constancy is truly remarkable. According to Harry Helson (1938) an illumination source instrument-measured as composed of up to

93% chromatic (colored) light will continue to be perceived as achromatic (white) provided it contains 7% "daylight" and is reflected by surfaces with a uniform reflectance (reflecting equally at all wavelengths).

The significance of the mechanism of brightness constancy is two-fold. First, it proves conclusively that there is not a one-to-one correspondence between sensation and perception since one object, perceived under demonstrably different lighting conditions, does not change its appearance (given time for the mechanism to adapt). Secondly, and perhaps more important, brightness constancy suggests that the eye possesses some means of evaluating the illumination context of a whole scene, without regard to the specific sensations of color. This is one of the great perceptual competencies of the visual system and although the information it yields is often ignored (as in the compensation called brightness constancy), at some point in the processing of visual information, it seems that the illumination context is sensed and evaluated for its relevance in the perception of objects.

Recall, from chapter three, that the color space of psychophysics is a three sided pyramid where luminosity measures the vertical dimension of depth (fig.47). If one takes a horizontal "slice" of the color space at maximum luminance (or maximum brightness), one gets a rounded triangular shape called the CIE chromaticity diagram. The CIE diagram is constructed from the trichromatic coefficients which are based on the spectral sensitivities of the standard observer.

The CIE system is a color stimulus description system as opposed to a color perception description system. A perception system, like Munsell's, is constructed on the basis of color samples arranged according to visible perceptual differences. The CIE chromaticity diagram, on the other hand, is constructed on the basis physical stimulus (fig.48). It is a graphical representation of a mathematical construct, adopted in 1931, to enable a visual scientist to specify the luminous flux of a stimulus in terms of expected color response. The spectrum, explicit in Newton's theory of color and comprised of the circuit of homogeneous colors, becomes the spectrum locus in the chromaticity diagram (fig.49). Colors are located on the spectrum locus according to their dominant wavelength. Dominant wavelength is the psychophysical correlate of the attribute of sensation called hue.

Dominant wavelength accounts for the fact that any given color may be composed of at most three wavelengths of light and that a theoretically infinite number of different three wavelength compositions may comprise any given hue (see above for a qualification of this presumption). This effect, where the light composition of hue is not deductible from the perception of hue, is called metamerism. It is a fact of visual perception markedly different from auditory perception where, for instance, a cord may be decomposed into its individual constituent elements because in the ear, all wavelengths (not just three) are registered independently by the hairs of the cochlea. The strength of the CIE system is that any combination of visible energies which give

rise to the sensation called color can be located in color space according to a combination of dominant wavelength and luminance (where luminance given in the dimension of depth and dominant wavelength is given in plan section, at the perimeter of the spectrum locus).

A gloss on how the spectrum locus works might go like this. Assume a visual scientist wants to evoke a sensation that in another context might be called scarlet but what, in this context, is called a target color. Since the sensing mechanism of the eye responds to a given color stimulus according to three variables (von Helmholtz' principle colors) the strength of response to the stimulus is estimated based on the intensity of luminance (which includes a factor for the target object's reflectance or transmittance) and the spectral distribution of the luminance. The hypothetical response is plotted on a graph representing all visible colors. A point on the graph is located that corresponds to the wavelength composition of the target color on three dimensions. Another point is located on the graph that specifies the wavelength composition of the light illuminating the target color. A line drawn through the two points outwards, intersects the perimeter of the graph. This intersection identifies the dominant wavelength of the target color (see fig.50). Dominant wavelength can be thought of as a means of expressing a trio of values extrapolated from the response curves of the sensing mechanism of the eye into a unitary value. The definition of dominant wavelength, however, is complicated by the inclusion of non-spectral colors along with spectral colors in the

chromaticity diagram.

Non-spectral colors are precisely the colors of light von Helmholtz added to Newton's color circle when he enlarged it to include purples. Purples are colors that cannot be defined according to their dominant wavelength because they are not homogeneous lights, being a mixture of red and violet. In other words, they are not part of the constitution of white light and cannot be measured independently. Therefore they are defined in terms of their complementary dominant wavelength. The complementary wavelength of a hue is determined by a line drawn from the target purple through the white point (defined as the color temperature of the illumination) towards the opposite side of the chromaticity diagram. Where this line intersects the spectrum locus on the side opposite, locates the complementary dominant wavelength.

All of the hues located in the region of the chromaticity diagram referred to as "non-spectral" must be defined in this way since these hues have no dominant wavelength in themselves, but they do have a complementary dominant wavelength, located generally on the greenish portion of the spectrum locus. Note that psychophysics gives a rigorous definition of complementarity symmetry through the white point, but note also that it makes no claim for the effect of juxtaposed complementary colors. There simply exists a boundary of seeable (colored) lights and a notational relationship among opposite dominant wavelengths.

The color space of pigmented colors is necessarily smaller than the boundary of the spectrum locus and complementary colors,

defined as pairs of colors that maximally enhance each other in the more restricted space of a pigmented color system, do not necessarily correspond to complementary dominant wavelengths. This is an instance where psychophysics, founded as it is upon the color matching of "unrelated" colors, is at a bit of a disadvantage since the effect of complementary colors, in the sense of mutually enhancing pigment pairs, is solely dependent on quantifying hues sensed as "related"[10] in the visual field. It is not that psychophysics cannot study this phenomenon. It can and does. But the spectrum locus was not designed in such a way as to offer a simple explanation for the effect of mutually enhancing colors.

Purity, like luminance and dominant wavelength is another term that belongs to the psychophysics of color. Given a target color there is a dominant wavelength and a color temperature to the source illumination that anchor two end points of a line on which the target color lies. If the distance from the source illumination to the color sample is (a) and the distance from the source illumination to the dominant wavelength is (b) then purity is the ratio (a/b)(fig.49). To say the same thing in a different way: all colors have a dominant wavelength (or a complementary dominant wavelength). Every target color can be matched by adding an achromatic illuminant to the dominant wavelength. The smaller the amount of the illuminant that needs to be added to match the target color, the greater the purity of the target color. Purity is a characteristic of color that sensation judges relatively, only approximate to overall brightness. Purity is considered the psychophysical correlate of saturation.[11]

Chromaticity is the word from which the chromaticity diagram takes its name. It is an absolute measure of the color quality of a stimulus without reference to brightness. Chromaticity is specified in the CIE coordinate system by reference to the x and y coordinates of the trichromatic coefficients and its specification brings out another important feature of the CIE coordinate system. Given two colors, the product of their mixture is located on a straight line drawn between the original colors. Using this feature of the CIE system the color resulting from a mixture of colored lights is predictable, ignoring brightness, from its' constituent colors.

The difference between purity and saturation is that purity is a psychophysical measurement of unrelated colors that identifies the amount of achromatic light in a color stimulus. Saturation is a description of the sensation, of the magnitude of hue. The difference between chromaticity and saturation is that chromaticity is a psychophysical measure of chromatic content without regard to overall luminance. Saturation is a means of describing the chromatic content among colors of equal brightness.

Notes to Chapter Four

1. I shall use "Primary" to refer to the general idea and "primary" to reference the embodiment of "Primaries" in particular systems.

2. Purple is Aristotle's term (which is different than Newton's term, see note 4 below) which he uses to describe the long wavelengths of color in the rainbow. Aristotle's "purple" is now typically rendered "violet" and sometimes even he substitutes violet for purple, confusing modern readers. This discrepancy between the name of a color and the color(s) it refers to is the source of a pervasive confusion in color studies. In Aristotle's case it points to the broad range of hues Greek color names designate.

3. There is a great deal of discussion in the scholarly literature about what color Alberti intended by ash or ashen (as Edgerton renders it) for the "earth" color. I have traced this discussion in detail elsewhere and the simple answer, argued by Jonas Gavel, is that Alberti intended a color we might call yellow ochre (see Gavel, 1979 pp.46-55 and 108-9). This is the simple answer but do not assume because it corresponds to what is now popularly understood to be one of four primary colors that it is obvious in Alberti's work.

4. It is interesting to note that Newton is credited with being the first person to use "orange" and "indigo" as color terms.

> "Orange and indigo Newton did not quite coin...But if he did not give the name, he at least supplied the local habitation...[O]range, and indigo thenceforth had their definite places in the spectrum. They became standard colors--a precise image every time one looked at a rainbow." (Stewart, 1930:74, see also Heifetz, 1994:68-70).

The words were in common circulation, orange as the name of a fruit, indigo as the name of a dyestuff and Newton simply appropriates them when he decided, for reasons that had nothing

to do with his theory of color, that he needed seven colors
colors in his spectrum.

5. Von Helmholtz typically used the word "primary" to describe his idea of what constitutes a Primary color, but this usage promotes confusion in an historical exposition of ideas about Primacy so I have adopted another word von Helmholtz only occasionally used, "principal" to name his primary colors. Where "primary" occurs in quotes from von Helmholtz I have not altered the quote.

6. Note the implied qualification of the assumption of an infinite number of homogeneous colors.

7. The anthropologists Brent Berlin and Paul Kay call their primary colors "focus terms" of which there are eleven: white, black, red, yellow, green, blue, brown, purple, pink, orange, gray. Focus terms are color terms that appear in a predictable order in almost all languages studied (regardless of language family) and are highly correlated to the technological sophistication of the culture in which the language is spoken. This is a gloss of Berlin and Kay's work that does not do it justice but since it is not part of my argument here and it will have to do.

8. I borrowed this fantastic string of color terms from Tung Yueh (1620-1686), The Tower of Myriad Mirrors, 1978. I modified the list in borrowing it but Tung Yueh provided the basic pattern. See figure 39 for another source of material for the rich vocabulary of color.

9. Luminous flux is only one of several "characteristics of light," correlate to "characteristics of radiant energy (in physics). For a schematic representation of these relationships see figure 44.

10. See Chapter Five for a discussion of the difference between related and unrelated colors.

11. R.W.G.Hunt (1977) makes a formal recommendation that purity should no longer be considered the correlate of saturation. As far as I know the CIE has not taken action on this recommendation and has yet to formally disjoin purity and saturation.

THE LAYERING OF COLOR SPACE

Roughly, by a complex system I mean one made up of a large number of parts that interact in a nonsimple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole. In the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist.

Herbert Simon (1962:468)

The exposition of "Color in black and white," up to this point, has been driven by rather abstract considerations of method, the physical basis of seeing and the role of language in the perception of color. I have followed a plan that reconstructs what Aristotle, Alberti, Newton and von Helmholtz had to say about the matter at hand, in the process defining key concepts. I have asserted that the process of sensing is as guided by the presumptions of perception--intentions, expectations, memories, ideas--as it is by the objects sensed. I have argued linguistic facility and visual experience interpenetrate to such a degree that what we can see is restricted by what we might say and have observed the inverse, that what we say is partially (or largely) circumscribed in what we see.

I have located the relationships between observer and observed and the different concepts of Primary color in four distinct historical periods and, by default, in four disciplinary

milieu. I have defined color, brightness, hue, saturation and distinguished sensation from perception, gray from grey, trichromatic processing from opponent processing, and apperception from perception. I have peppered the exposition with diagrams in a attempt to make the central concepts less abstruse, but, in the end, the suggestions, assertions and arguments are difficult, "problematic," as academics like to say. One problem, central to this essay, is that color seems unambiguous in the eye of the beholder and most attempts to render it, in scientific and artistic terms alike, at some point seems to be just so much verbiage. This is why, at the beginning of this essay, is a story.

I imagine in my mind's eye the entire weight of methodological presumptions, historical exposition, and necessarily reductive definitions to be balanced by one short tale. But for the requirements of academic discourse and the not altogether accidental differences between the conventions of the essay and the conventions of ekphrasis, I would submit the story for your consideration, make a date to discuss it over a bottle of nouveau Beaujolais and be done with it. It is just that simple and it is not that easy. This is as it should be. As I lay the groundwork for a discussion of vivid architecture, I will turn from the general consideration of abstract color concepts to a consideration of two colored objects; one a painting by Claude Monet, Grainstacks (End of Summer) (1890-1891), and the other sunflower at sunset yellow. In the case of Grainstacks I plan to use the painting as a touch stone around which to organize

the further exposition of concepts required for a discussion of vividness in color; the framing of the scene, the reflection and transmission of light, the detection of brightness distributions, the relation brightness+hue, the description of adaptation, the displacement of the seeing "I" and the rendering of colored form. Finally I will turn in chapter six to the story "Sunflower at sunset yellow" and present a plausible description of the layering of sensations and perceptions that constitute an impression of vivid color.

Monet's Grainstacks

In the late 1880's and at the beginning of the 1890's Claude Monet (1840-1926; fig.51) began painting groups of paintings of a single scene under different atmospheric conditions. These canvases, collectively known as the series paintings, contain some of Monet's most remarkable work. Grainstacks, painted in 1890-91 (in the collection of the Art Institute of Chicago; color plate I, p. and fig.52), is from the third series to which Monet put his hand. Grainstacks (End of Summer) is one of at least thirty canvases executed at Giverny, almost literally outside the door of a house Monet had just purchased (figs.53,54)[1].

The Grainstack paintings are "important". Various groupings of the series were exhibited, to wide acclaim, in France in the 1890's. Monet seems to have found the techniques that he would repeat in other great plein aire series. Kandinsky attributed his realization of the possibility for a completely non-representational painting to Grainstack in Sunlight (1891)[2]. The

series paintings were Monet's reaction to the issue of "scientific" painting, a live question in French avant garde art of the time.

Georges Seurat A Sunday on the Island of the Grande Jatte (1884-86) in the eighth Impressionist exhibition held in May and June of 1886. It created a sensation.

> Executed by juxtaposing hundreds of small touches of paint in a broad range of of complimentary colors that attempted to describe the essential components of perceived color-light in a "scientific" way, Seurat's huge canvas challenged the basic premises of the Impressionist's style and orientation and was immediately recognized as a new direction for avant-garde painting. (Tucker, 1989:19)

Two of the original group of Impressionists, Camille Pissarro and Paul Signac, abandoned Impressionism for the new pointillist style, and in the process turned on Monet. Pissarro broadcast his opinion that Impressionism was "romantic" and Monet's brushwork "rancid". Monet, in turn, refused to participate in the eighth (and final) Impressionist exhibition.

Just exactly what makes Seurat's work "scientific" has never been clear to me. Seurat died young so his entire oeuvre consists of sixteen paintings many of which I have seen. The figures look stolid, the modeling artificial, and the colors washed out. To be fair there is a pearly quality of light in some of his work, for example une Baignade a Asniers (fig.56), which is impossible to capture in reproductions, but La Grande Jatte looks, at a sufficient distance, harsh. It is, of course, amazing that Seurat could create a huge canvas where the entire effect of a recognizable scene disintegrates as one moves closer

and closer to the painting, but the device of optical fusion (and the fact of size) on which the painting depends for its impact hardly constitutes a scientific art--after all, around 1704, Jacques Christophe Le Blon developed and patented a process of printing mezzotints in color that also utilized "pointillist" optical mixture, to create an early form of color printing (fig.57).

Another reason Seurat's work might have been interpreted as "scientific" was because he referred directly to, almost "quoting," the work of the chemist Michel Eugene Chevreul (1786-1889). Chevreul was appointed to the Gobelin tapestry works because there was thought to be a technical problem with the formulation of dies used to color yarn in tapestries. Chevreul did in fact find a problem with the formulations for blue, violet, gray, and brown but he could not discover the source of complaint concerning black. This led him to a study of color contrast, where he discovered that the strength of color depends on the juxtaposition of color patches. Seurat adopted this idea of color contrast from Chevreul without quite understanding it. He assumed that by juxtaposing complementary colors--colors that in contrast heighten the perceptual effect of each other--he could recall for his viewers the most saturated colors possible. This technique it turned out, de-saturates color at a viewing distance greater than that of optical fusion, where groups of juxtaposed points or pigment tend to gray out the color, destroying the heightened effect of perfectly complementary colors juxtaposed in distinguishable patches.

In the end, it seems that Seurat's painting was "scientific" because the critic Felix Feneon, said it was. In the original argument presented in the pamphlet *Les Impressionnistes en 1886* Feneon laid down the principles by which the Neo-Impressionism could be separated from Impressionism:

> Feneon declared that Seurat's divisionist art relied on structure and science, not intuition and chance; that it resonated with references to history and past art, not the immediate and the mundane; and that it laid claims to higher realms and principles, to museums and the eternal, not to bourgeois drawing rooms and fleeting moments in time. It was therefore superior to Impressionism and deserved to be recognized as the most innovative and up-to-date style of the day style of the day. (Tucker p.19)

Tucker's argument in Monet in the 90's is that the series paintings in general, and the Grainstacks in particular, were Monet's reaction to the challenge of the "scientific" artists Seurat and Pissarro.

> These questions [how to render light], of course, had long been fundamental to Impressionism. But when they were posed anew by Seurat and his followers, particularly Pissarro, they clearly caused Monet to test his former answers and to see how many new ones his Impressionist style might offer. (Tucker p.23)

Unfortunately Seurat did not live to continue the conversation beyond 1891 but, fortunately for us he pressed Monet to re-think his painterly principles and re-present the results in a series of series that are unprecedented in the history of painting.

The series paintings, in their contemporary critical context, seem to be posed as an extended scientific experimental program intended to study the effects of the relationship among

light, color and form at a given moment, at a given time, in a given place. Monet's studies of the play of light over Rouen Cathedral seem indeed to be fantastically precise, sometimes even titled with the time of day; but, they are not and were never intended to be, objective scientific records that prove anything. Monet was a painter and he was perfectly capable of shifting a shadow, repositioning a haystack, and substituting a color in any given portion of the painting for the sake of the aesthetic whole. Tucker's argument is that Monet was not only (or even primarily) concerned with the play of light. The paintings were intended to evoke a response and part of the conscious response was supposed to ascribe significance to the scene represented. Tucker argues:

> Thus, his series painting of the 1890's are not just about atmospheric envelopes or instantaneity. They operate on a larger level "beyond their apparent subjects," as Desire Louis suggested above. They are, as we shall see, Monet's deeply personal, but highly informed, responses to the challenges of fin-de-siecle France. (Tucker p.15)

I am, on the other hand, not concerned with the the challenges of fin-de-siecle France[3] and will concentrate on an interpretation of Grainstacks (End of Summer) for what it suggests about the perception of color at the gloaming. I will adopt, in turn, the point of view of a photographer, a physicist, a physiologist, a psychologist and a painter reflecting on the terms and techniques of their own work as a response to the painting. Each persona will discuss some aspect of the painting as a means of clarifying one or two concepts central to the discussion of

"Sunflower at Sunset Yellow" in chapter 6.

[n.b. This is supposed to be a colored print of Claude Monet's Grainstacks (End of Summer). It is placed here so that one might easily refer to it during the exposition that follows. I think one can follow the analysis without a color reproduction to refer to and do not disdain this humble photocopy. There is a great deal of information in the high contrast black and white image.

A photographic consideration of lighting[4]

Photography is important aspect of the study of color. Much of the research that has contributed to the development of psychophysics in America in the mid-twentieth century was motivated by a burgeoning photographic industry and financed by hobbyist photographers. While the hobbyists' funded the development of ever more sophisticated films, the most technically advanced films were (and are) only available to professionals, who guard the technology of their craft much as medieval dyers protected their livelihood by not discussing trade secrets. Notwithstanding the difficulty of getting professional photographers to talk about how they achieve sometimes spectacular effects in their work, some of their techniques are generally known and much of their specialized vocabulary is borrowed, occasionally from painting, usually from physics.

A photographer reflecting on the techniques of her work in the context of Monet's painting might discuss the difference between shooting with color and shooting with black and white

film, the nature of contrast in photography and the nature of diffuse light. The difference between the response of color film and black and white film is interesting because black and white film allows one to sample a brightness distribution of light in any of a number of ways depending on where one desires detail--in the shadows or in the highlights. Color film is less forgiving; exposure must be dead on if the colors are to be accurately rendered.

Black and white film samples only a portion of the scale of brightness in a scene, especially a scene illuminated by midday, cloudless, sunlight. Roughly speaking, black and white film can record the gradation brightness in shadow, the gradation of brightness in the mid range, or the gradation of brightness in highly illuminated areas, but not all three. When shooting a scene where the brightness range is greater than the range of the sensitivity of the film, a photographer picks the range in which she desires detail and adjusts aperture size and exposure times so as to capture the desired range.

Considering the landscape of Grainstacks in this context, a photographer might wish to record detail in the wispy clouds Monet only hints at in his canvas. She would meter on the sky and close the lens down a couple of f-stops. In this situation the lightest part of the sky, the white wispy clouds, would be rendered on the black and white film in detail but the shadow of the grainstacks and the darker portions of the hill behind would go entirely black, showing no detail. The long highlights falling across the fields and the sun side of the grainstacks would

show some detail but generally the landscape itself would be in shadow, especially through the line of trees in the middle distance. Depending upon how the features of the dark landscape were framed, this might be a dramatic photograph in a low key, dark ground with a light sky showing detail in the clouds.

At the opposite extreme a photographer might decide to expose the film for the shadows. In this instance she would meter for the darkest part of the scene and open up the lens a couple of f-stops. (The darkest part of the scene is probably the shadow cast by the big tree just to the right of the large grainstack.) Shooting for detail in this area of the scene would considerably lighten the entire landscape visible in the middle and far distance, probably obliterating the horizon line to the right of the large grainstack. The self shading side of both grainstacks would show a lot of detail as would their shadows cast on the ground but the highlights on the ground would be without detail--"blown out" she would say--as would the sky, which would be entirely without gradation. This black and white photograph would be dramatic in the opposite extreme--high key--focusing our attention on a distribution of texture in parts of the landscape formally in shadow and the sky would be featureless.

In between these two extremes would be an exposure setting that captures some detail in the shadows and some detail in the highlights of the landscape but, no detail in the sky, which would still be too bright for the film to articulate. This exposure setting would conventionally be thought of as the

"correct" exposure since it averages the light in the scene.

One object in Monet's landscape which this exposure would show clearly is worth noting. At virtually the exact center of the canvas, is a patch of white that in both the low and high key versions would be obscured. In the low key photograph it would go dark and blend in with the middle distance (fig.55). In the high key photograph it would tend towards white and get lost in the highly textured middle ground.

An "average" exposure would best articulate the barn at the center of Monet's canvas. This is not to say that the "correct" exposure always makes for a good black and white photograph. Actually, it rarely does since good photographs depend on the compositional eye of the photographer, her choice of a frame for her subject and her ability to visualize the arrangement of visual texture, white, black, and color in the finished product. The point is, because black and white film records only a brightness distribution, photographers get to choose the balance of light and dark that will be sampled on the film. Color is not so forgiving.

Where black and white film consists of a single layer of light sensitive emulsion, color film consists of three layers, each sensitive to light of a different spectral distribution. The accurate rendition of color in the final image is dependent on an interaction among the different colored layers. One may think of the layers as sampling different brightnesses of specific monochromatic hues, just as black and white film samples only achromatic brightness. When these layers are reconstructed

in the process of developing the film, any deviation from perfect exposure on one of the layers will shift not only brightness but also the color rendition of the entire assembled image in a way that is noticeable to a color normal observer. Therefore, color film reproduces color correctly only in a very small window of exposure, which is not variable according to the portion of a scene one wishes to highlight.

Using the example of Grainstacks the precise correct exposure of the original scene might yield a picture close to colors in the painting, with two exceptions. The colors on the shadow side of the large grainstack, instead of shifting towards the pastel pink would probably be a darker brown, in other words, more in shade and therefor showing less detail and less color. Furthermore, the hill visible to the left of the smaller grainstack might not be so clearly blue and violet. (I am not saying these colors were not suggested to Monet by the colors he noted in the landscape, only that color film could not capture them, due to the nature of color photographic technology.)

As a practical matter, most hobbyists ignore color deviations, and happily shoot color film at all times of the day. But professional photographers, often shooting for reproduction, cannot afford this luxury. They almost always use color film (when shooting under "natural" lighting conditions) when the brightness contrast in a scene is restricted to a range which the film's sensitivity can encompass, so as to be able to render color most accurately. Typically they shoot--as Monet painted this painting--in early morning, early evening, or under condit-

ions where the direct light of the sun is diffused.

Pick up any glossy magazine and look at the advertising photographs which are taken out of doors. Try to read the time of day in the photographs. It is not very difficult. The most obvious clues are provided by the projection of shadows. When the sun is high in the sky the shadows of objects are projected downward at a slight angle, depending on the precise time of day. Called flat lighting, this situation does not provide very good information for the decoding of volume by gradations in the brightness of surfaces. Shadows projected in this way tend to flatten out a face, for example, by obscuring its' salient features. The shadow from the brows obscure the eyes. A shadow from the nose may obliterate the definition of the lips, joining the convexity of the tip of the nose to the convexity of the chin, shadowed in turn by the concavity of the neck. The cheeks may not cast a shadow at all and therefore it is difficult to tell, on the basis of visual evidence alone, whether they are absolutely flat, slightly concave, or slightly convex.

Flat lighting also makes it difficult to distinguish the object and its background. The direction of the light, in the case of flat lighting, by casting the shadows mostly downward does not throw a shadow on the side of the face. This means that the face itself is difficult to distinguish from whatever it is in front of, assuming the background is of roughly the same brightness, as is often the case. The problems of flat lighting are difficult to catalogue in detail because all depends on the relative spatial position of light source, object lighted, and

viewer; but, one can grasp the diminishing of volumetric information that flat lighting causes and the way contrast helps viewers decode formal information from brightness information in representations. Photographers, therefore, prefer twilight lighting even to perfectly diffuse lighting since diffuse lighting tends to obliterate shadows, so important for the visual decoding of pictorial representations.[5]

Monet's Grainstacks illustrates well the way, when shooting color film, one trades the ability to capture differences in brightness for the ability to render differences in color. The natural lighting situation that allows one to do this is when the absolute intensity of light is compressed into a relatively small range and there are shadows. This happens at twilight, either in the morning or in the evening, and Grainstacks is a particularly good example of the nature of diffused light in terms of the rendition of both brightness and color.

A physical consideration of light[6]

A physicist considering Grainstacks (End of Summer) would have little to say about color, but she might have a great deal to say about light: the difference between reflected and transmitted light, the difference between diffuse and spectral light, the difference between diffusion and scattering, all relative to incandescence, a distribution of spectral energies that, in human observers, produce the sensation of color. She might still use the word "color" but it must be tacitly understood that rather than discussing the sensation of color she is discussing

the spectral composition of radiant energy.

Incandescence is a theory of the relationship between heat and light. Black body radiation models this theory. A resistor that glows different colors with increased temperature is typically used to illustrate the theory. A cold resistor is initially black, illuminated only by incident light. As the metal is heated it becomes self luminous, glowing orange, white, and finally bluish white. The absorption of energy by the metal increases the random motion of its molecules, which emit photons, which are perceived by the eye as light tinged with a color. The source of the heat does not matter it can be mechanically, chemically or electrically induced. What is important is that there is a precisely definable relationship between the absorption of (heat) energy and the emission of (light) energy in black body radiation. The theory that accounts for black body radiation is called the quantum atomic model.

In the atom, protons and neutrons cluster to form a nucleus to which electrons are bound in shells, probable electron locations (fig.58). Electrons jump between shells according to quanta of energy absorbed by the atom. As the electrons, excited by absorption of energy, move among orbits according to predetermined stepwise jumps, packets of energy are shed in the form of photons. When the wavelength of the energy shed is within the range of human visual sensitivity (400-700nm) the energy is sensed as light and is called incandescence.

Incandescence produces "white" light only roughly speaking (fig.59). "White" light is a distribution of a variety of

spectral energies. Newton's fundamental discovery was that what humans sense as "white" light is in fact comprised of many wavelengths[7]. Armed with this observation Newton demonstrated colors are neither created nor destroyed. Furthermore, when he says the "rays are not colored" he is implicitly dividing the visual manifestation of energy from the physical behavior of light. Ultimately physics ignores the visual manifestation of energy, though it deals extensively with the interaction of light and bodies; bodies that reflect light and bodies that transmit light.

In some sense this is an artificial distinction because, as Newton showed, refraction (the differential bending of the constituent rays of light when it passes from one medium into another) and reflection (the turning back of rays of light at a boundary between media) are special conditions of a more general law that governs the interaction of light and objects (fig.60).

The distinction between diffuse and specular light (fig.61) also describes an interaction among light and bodies but the terms are somewhat confusing because they may be applied, under different conditions, to both transmitted and reflected light. Diffuse transmitted light is radiant energy that has been diminished by an interaction with particles in the medium through which the light is passing (fig.62). The particles deflect some of the rays of light, diminishing its overall intensity without changing its spectral distribution.

Light reflected by objects may also be said to diffuse light according to the faceting of their surfaces. An object

that diffuses light receives radiant energy, reflecting the light by virtue of the irregularity of the surface. Such surfaces are described as matte surfaces (fig.63).

Specular reflectance is a condition complementary to the diffusion of light by surfaces. Specular reflectance is where the smooth surface of an object reflects light preferentially, maintaining the ray's directional coherence, and which is perceived as a highlight (fig.63). Polished metallic surfaces (including mirrors) are smooth and the reflection of light rays off them tends to maintain its directional coherence called a highlight or a "burn" (in photographic terms).

In the context of transmittance, scattering is the complement to diffusion. Diffusion is a deflection of radiant energy by particles in a medium where the particles are larger than the longest wavelength of the light. In this case the light is simply diminished in intensity. Scattering occurs when particles deflecting the radiant energy are the same size or smaller than the constituent wavelengths of the light. Scattering alters the spectral distribution of the incident light (and its perceived color) by decomposing radiant energy of a given spectral distribution into its components, preferentially transmitting some components to the sensing instrument and deflecting other components out of the line of sight (fig.64).

The light situation in Grainstacks may now be described according to the quality of reflected and transmitted light and according to diffusion and scattering of radiant energy in the scene. In general, the light shown in the painting is diffused

and scattered. The light is diffused since the range of contrast in the scene is greatly diminished. The contrast range is diminished because the source of light, the sun, is low in the sky and the overall intensity of radiant energy is reduced by the mass of atmosphere the light must traverse in order to reach the scene. The light is also scattered by dust particles and moisture in the atmosphere which changes the spectral distribution (color) of the light illuminating the scene. The effect of scattering is clearly visible in the sky portion of Grainstacks. On the right side of the painting the atmosphere takes on a yellow cast because portions of the "white" light of the sun that would normally include energy wavelengths we would code as red, green, blue (and sum with yellow to white) are scattered out of the line of sight. A similar condition is visible towards the upper left corner of the painting, where just a hint of blue is detectable. In this part of the sky, radiant energy from the sun has been decomposed by scattering so that all that is left from the original composition of the light are a spectral distribution of rays we perceive as pale blue (cyan).

The effects of light in the landscape below the horizon in Grainstacks is several orders of magnitude more complex than in the sky due to myriad reflections, although it is still describable in general terms. Note how the yellow atmosphere on the right seems to blur the horizon between the sky and distant hills. To some degree this is a convention of Monet's that helps separate the foreground grainstacks from the background hills, but it is a convention that accurately reflects the tendency of

an intense source of light that is rear projected onto particulate matter in the atmosphere in such a way that scattered light in the sky mixes with the reflected light of the hills.
Von Helmholtz called it irradiance. A related condition is observable on the hills at the other side of the frame. Here the incident light is not so intense, so the sky does not spill over onto the hills and the color of distant hills is given a bluish cast which accurately reflects the tendency of diffusely reflected, diffuse (transmitted) light, to scatter slightly towards the blue and violet. One may observe a similar effect in the largest tree visible just to the left of the large grainstack. The shadow of the tree is given a dark bluish/violet cast, partially to harmonize with the colors used to render the hills, but also because what little light that is reflected from the shadow of the tree is shifted by scattering in the same way as the light from the distant hills is scattered: by particles in the intervening atmosphere.

The large tree also shows a little green on the top, where there is enough intensity of light from the sun shining on the leaves to reflect, through the intervening atmosphere. The green of the foliage is diminished by diffusion and is therefor rendered darker than other greens also in the middle distance (but in front of the tree) and especially darker than greens in the foreground.

Finally, highlights on the large tree and the other trees in its neighborhood are suggested in yellow. This is explainable, though not rigorously describable, as an odd case of

specular reflection. The visual clue of a specular reflection is that a specular highlight takes on the color of the irradiating light rather than the color of the object. It is a specular reflection because the coherence of the illuminating light is maintained in the highlight of the trees just as it would be in the reflection from a glossy surface.

Actually a keen physical observer (or a reckless student) might sense an incongruity in the rendering of the light in Grainstacks. The specular highlight on the trees does not duplicate the highlight on the grainstacks. The duplication, in itself, is not absolutely necessary, since the highlight edge of the grainstacks might be reflected orange by the hay, while the highlight visible on the trees might be a product of rays scattered towards the yellow, specularily reflected off the leaves. This would indicate that the source of the orange highlights is a diffuse reflection and that the source of the yellow highlight is a specular reflection, and the orange still seems a little out of place. One can not quite account for it using the atmospheric conditions rendered in the painting.

It is possible that the sunlight is scattered towards the orange and that both highlights are specular reflections of differently constituted scattered sun light, but this interpretation is contradicted by the evidence of the shadows. It would have the sun setting further to the right from where the shadows indicate it is setting. If the sun is setting outside the frame in the direction the shadows indicate it is, why is there no hint of the orange cast visible on the highlights of the grain-

stacks, in the scattered sunlight of the sky or the specular reflection of the trees?

To be sure, this is an insignificant criticism of Monet's rendition of the colors in the painting. A slavish rendering of the light conditions would probably hurt the painting because the oranges and pinks in the hay helps clearly differentiate the grainstacks from the background. It may not even be a discrepancy at all, but a strict accounting of the light context of the scene indicates an incongruity in the rendering of the highlight on the grainstacks.

We must also account for the blue/violet cast of the shadows thrown by the grainstacks in the painting. It is well known to painters since Leonardo da Vinci first noted it, that the shadows of objects take on a bluish cast. Light from the sky irradiates (or fills) the shadow of objects. The sky appears blue due to the scattering of sunlight. The light of the sun at twilight, Monet suggests in the sky and on the specular reflections of the trees, is yellow. Where the yellow primary light is blocked by the grainstacks the blue secondary light of the sky provides alternate illumination. Under mid-day lighting conditions this effect would be very subtle. The effect is very pronounced in this scene because the overall brightness of the landscape is greatly diminished due to diffusion. In other words the absolute brightness of the scene is not so far removed from the brightness of the shadow. Therefore the shadow takes on the color of the dome of the sky.

Even though there is no color in physics, one way phy-

sicists study the atmosphere is according to the colors visible under different conditions. The variables of these conditions include the distance from the earth to the sun, the solar declination, the latitude and longitude of the observer, their height above sea level, the altitude and azimuth of the sun, the inclination (tilt) of the surface receiving light relative to the horizon, the diffusion of light by pure atmosphere (Rayleigh extinction), three variables expressing the water content and turbidity of the atmosphere, the ozone content of the atmosphere, the effect of cloudiness and the albedo of the ground. It may be a bit of a stretch to imagine some of these same observations applied to the painted representation itself but at least one very important observation surfaces from this analysis.

There are two distributions of radiant energy simultaneously present at the gloaming. One might be called the color of the setting sun. This color typically ranges anywhere from red to orange to yellow depending on the specific conditions of scattering, and in this painting it is suggested by contradictory clues in the spectral highlights. The other distribution of radiant energy ranges from achromatic to blue light, depending on the amount of cloud cover and on the scattering of light from the zenith. In Grainstacks the clue for this color is visible in the shadows which are markedly blue.

These two conditions exist in some tension depending partially on the height of the sun above the horizon. Twilight conditions may be said to prevail from when the sun falls to within

fifteen degrees of the horizon until the onset of astronomical night, when the portion of the earth visible by an observer is no longer irradiated even indirectly by light from the sun (approximately twenty minutes after sunset). During this time, shorter in winter longer in summer, what colors the eye sees is greatly influenced by light of two different and very pronounced spectral compositions. Furthermore the intensities of the different spectral compositions at twilight can be in rough parity a condition which is not the case when the sun is higher in the sky.

A physiological consideration of brightness[8]

This physiological consideration of Grainstacks is prejudiced by the findings and assumptions of the computer vision research of David Marr (1939-1974). His attempt to construct machines that process visual information lead him into an investigation of the mechanisms of sensation at an early level of visual processing. Most importantly, he assumes (1) that the structure of images of the world are related to the structure of the world and (2) that images are modularly constructed. The modules are "discreet processes that can be separated and implemented as nearly independent of one another as the general task allows" (Marr,1982:102). This approach seeks to discover symmetries between the objective world and visual representations of it. Curiously there is not much account taken of color in this approach, and that is why it calls for some speculation based on historical precedent, and an argument.

The historical precedent concerns the relative roles of

color and form in psychological investigations. There seems to be a pervasive bias in psychology towards the study of form. Psychologists (and computer vision researchers studying physiology) would probably deny this, but their behavior tells a different story. Rudolf Arnhiem and J.J. Gibson present cases in point. Arnheim was a scholar whose work bridged the psychology of perception (from a Gestalt point of view) and the perception of art. His book Art and Visual Perception (1954) contains a chapter on color which he routinely included in the courses he taught at Berkeley and later, at the University of Michigan. I have it on the authority of his last Ph.D. student, Karen Kleinfelder, that he was unhappy with this chapter of the work and that he often arranged to be out of town on the days this material was presented, leaving it to one of his graduate students to teach these classes. Similarly, J.J. Gibson in an early work The Perception of the Visual World (1977) discusses color at the beginning of the book and implies that his approach would be applied equally to the perception of color as to the perception of depth. He subsequently ignores the problems of color perception. Furthermore, according to William Mace (personal communication) no one concerned with an "ecological" approach to perception who is currently researching color.

The perception of light and color seems to be a nearly intractable problem that many thinkers have considered and then backed away from. Alberti is another case in point. His theory of color is important because it signals a shift in the dialogue about color in painting from a narrowly practical treatment of

painting as a craft to a broadly scientific consideration of nature. Note that this occurs in the context of his exposition of perspective and it is not as decisive a contribution to painting as is perspective. As Casper Hakfoort (1988:82) argues, Newton also seems to have formulated his ideas about scientific method in the crucible of his work on color. But the Opticks remains a work more difficult and inaccessible than even the Principia, a book about the physical basis of motion.

Von Helmholtz believed that objective color was richer, by one dimension, than subjective color but that the sensation of depth completely represented physical reality. Marr follows suit assuming 'the main job of vision is to derive a representation of shape' (p.36). The point is that color always seems to play second fiddle to other considerations such as perspective representation, motion, depth and shape. This indicates the inherent difficulty and insubstantiality of color as a subject (and as an object of perception).

The argument follows from the historical precedent. Marr argues that the theory of color vision is in an "unsatisfactory" state, one where the mathematical equations that predict color from stimuli are merely descriptions of color vision not theories of it (p.252). A true theory of color vision, he says, would be a computational model based on particular assumptions about the physical world and not just the phenomenological description of a collection of independent experiments.

David Marr enumerates the assumptions built into his theory thus: (1) information cannot be created, (2) an overall under-

standing must be constructed from the bottom up, (3) that different kinds of explanations are required at different levels of the description and (4) that, in principle, the micro and macro descriptions of the external world are consistent. Marr is investigating light and the neural decoding of intensity changes that may be assembled into the perception of depth and spatial extension from two dimensional retinal images and like Gibson and Arnhiem, apart from the brief section in which he argues current color theory is unsatisfactory, he does not deal with color.

Notwithstanding the absence of color theory in computer vision studies, I consider Marr's contribution very important in the study of color for two reasons. First, even though the computer vision physiologists have not incorporated color per se in their models, they are studying the interaction of light and objects at a very basic level of visual processing. They are investigating the ways the perception of surface, form and depth are constructed from achromatic color and at least one of the general principles of this approach may be incorporated into the the study of color. I am referring to the principle of modular design of the mechanism of perception. Marr assumes that there are only weak interactions between modules because in the evolution of perceptual mechanisms a small change in one module would not necessitate compensatory alterations in other modules, which would retard development. His argument echoes Herbert Simon's (b.1916) example of the evolutionary advantage of hierarchical development in complex systems.

Simon (1962) considers two different watchmakers. One assembles a watch one part at a time from beginning to end. The other assembles parts into sub-assemblies that are then assembled into the finished product. The first watchmaker, upon experiencing an interruption, would lose all of his work to date since the moment he turned his attention elsewhere the incomplete assembly would disintegrate into an incoherent mass of parts, forcing him to start over from the beginning. The other watchmaker who assembled his watch from sub-assemblies, upon being interrupted, would only loose the sub-assembly upon which he was working. By analogy, a complex system that evolved based on a modular design would have an evolutionary advantage since the improvement of one part of one module would improve system performance without necessitating the alteration of all subsequent related parts.

A modular design of the mechanism of perception provides a performance advantage in yet another sense. In a complex visual recognition task information about objects is assembled from a discrete sampling of the visual array. In most situations the sensing eye takes notice of the discontinuities present in the scene, filling in portions of the array it has not actually sampled based dynamic visual sensation. A case in point is the blind spot. In the retina, where the blood vessels enter and the optic nerve exits the eye, there is a region that contains no rods or cones, nothing with which to sense the presence of light (fig.65). Yet, there is no perceptual evidence that part of a scene is "missing." This is a strong indication of the way we

fill in incomplete information in visual processing.

Given the ability of perception to construct a scene by "filling in" it is likely that successive fixations sample only differences. Therefore when visual sensation encounters an "unexpected" bit of information (sensation different than in the previous fixation) it is not required to scrap all of the information so far collected. In a modular system all that needs to be further processed is the information in the module contradicted by the the most recent sample.

Using Grainstacks as an example, assume one is scanning the center portion of the painting from left to right. Initially the distant ridge occupies about one fifth of the horizontal expanse of the frame and, although it is interrupted by both grainstacks, a first approximation of the scene indicates that the distant hill is rendered as a band that stretches all across the landscape. In other words, on first viewing, one might ignore the subtle evidence that there exists in the middle distance a band of trees interposed between the grainstacks and the ridge. This "mistake" might persist as the roving eye samples shadows cast by the larger stack, the hint of blue sky, the odd clumps of chaff scattered about, Monet's signature and date, until finally a large tree is encountered. The tall tree is evidence that there exists an intermediate plane in the middle distance, a line of trees that were initially overlooked. This new discovery does not necessitate rejecting all of the evidence collected concerning the color of the sky, the shape of the grainstacks, the direction of the shadows, the date of the painting, etc. One

simply updates the module that identifies the relative distance of objects in the frame in order to account for the new information.

As it happens, Monet's trick of blurring the middle landscape into the distant landscape encourages us to look again, more carefully, at the portion of the painting where the green of the tree line emerges in fits and starts from the green violet of the distant hills. This interruption of the large scale activity of constructing the subject of the representation, momentarily disengages the roving eye from a global consideration in order to engage it in a local detailed inspection of the color and brushwork in a tightly defined frame around the top of the smaller grainstack. The viewer might even move physically closer to the painting so as to be able to interrogate a series of relatively small portions of the canvas without regard to the overall shapes present.

This transition, from a large frame of reference concerned with general forms to a smaller frame of reference concerned with the observation of minute patches of homogeneous colors, mimics a mechanism involved in the early stage of processing shape from change in brightness. That Monet manages to draw the viewer into his representation by clueing the visual system to switch scales, constitutes part of his competence as a painter. Monet keeps us interested in what we are seeing, without regard to our interest in the subject matter, by a deft mimicry not of the scene but of the way we look at a scene.

In other words, assuming our attention has been directed

towards the painting in the first place, Monet clues us on how to reconstruct the scene by providing visual information on at least two different scales. The ambiguity of depth information at one scale encourages us to consider the shape information conveyed by patches of homogeneous color at a smaller scale.

The precise way that the visual system uses these spatial filters the second contribution with which I am concerned. Marr models how the filters work, deriving shape and spatial information from changes in brightness and although he does not discuss this in the context of color, I will attempt to show its relevance for color perception.

Marr "divides the derivation of shape information from images into three representational stages" (p.37), the primal sketch, the 2-1/2 dimensional sketch and the fully three dimensional representation. The primal sketch is a two dimensional image which gives information about intensity changes from which we derive shadows, edges, textures terminations and discontinuities.[9] The 2-1/2 dimensional sketch yields information about surfaces in a viewer centered coordinate system, including orientation, distance from the viewer, reflectance and some coarse description of prevailing illumination. The three dimensional model is an object centered representation of structure and viewed shape including some description of the surface characteristics of the object.

Marr's finding that bears significantly on perceived color, has to do with the most primitive level of the primal sketch, the visual sampling of brightness changes in the visual array.

Marr argues that in the initial stage of retinal image processing, at every point in the retina, there are four size-tuned filters which analyze the image. Two of the smaller filters "display relatively sustained temporal properties, whereas the larger two are relatively transient" (p.62).

Marr presents evidence that the central part of the receptive field in the smallest filter corresponds to a single cone or picture element and assumes that the subsequent filters correspond to fields of 6, 12 and 24 "pixels" (fig.66). He shows that the receptive cells are circularly symmetrical and, in terms of the mathematical model, correspond to the lowest order isotropic Laplacian operator (fig.67).

Moving from an analogue or continuous representation to the discreet symbolic representation of the raw primal sketch Marr suggests, with strong qualifications, that there may be no loss of information from the scene to the image. In other words, from a representation of brightness on the retina the visual system builds a symbolic representation of shadows, visible light sources, illumination gradients, changes in orientation and distance from the viewer, and changes in surface reflectance. The visual processing that yields this information is an operator which processes the change in the change in brightness (or the second derivative of brightness distribution) at four different scales. The information at different scales, when it coincides, "indicates the presence of a change in the image that is due to single physical phenomenon (a change in reflectance, illumination, depth, or surface orientation)" (p.70, Marr's italics).

The significance of this model for the representation of color is two-fold. First, it provides a firm basis for a mechanism in visual perception that samples color at different scales. This has been a persistent problem. It has long been assumed that the eye samples general illumination in a scene as well as local color but there was no foundation on which to model the effect. Secondly, it suggests the way in which a representation such as Monet's Grainstacks conveys the conditions of the general illumination.

Atmospheric physics explains that a twilight scene includes colored incident light that reacts with local conditions so as to alter local colors. Often the observer is not directly aware of the illumination context of a scene or is tricked into thinking the light context is the same under different conditions. Monet must assume that the painting, as the object of perception, is not going to be illuminated under conditions identical to the conditions he painted under. He must provide some clues in the painting so that the observer correctly identifies the illumination context of the representation separately from the different illumination context under which the painting is viewed. Monet does this in two ways, at two different scales.

The obvious way he communicates the illumination context of the scene is in his rendering of the sky, with a yellow cast, and in the blue color of the shadows. This interpretation is, of course, supported by a reading of the shadows which indicates the sun is low in the sky. This interpretation of the painting is a product of the large scale structure of the image, which

is temporally transient. There is another clue in the painting, which at a small scale provides a subtle (but more temporally sustained) clue to the illumination context.

Consider the gable wall of the barn at the center of the picture. Since it is an insignificant part of the landscape, a conscious recollection of elements in the painting might not even mention this structure. Although, I believe, it plays a very significant role in establishing the illumination context of the scene. The full significance of this patch of white tinged with blue will become clear after I have discussed brightness constancy and chromatic adaptation, but I want to call attention to it as a white reference point here.

The barn is a "white reference point" in the representation because the barn is the only small scale element in the painting that is even close to white. The eye picks it up as a white reference and norms the perception of color in the whole image to that point's brightness and chromaticity. Why the eye does not use the sky as the white reference has two answers. First, in real landscapes (as opposed to painted ones) the brightness of the sky is too bright to exist in the same frame of adaptation as the landscape. If we used bright white sky as a white reference virtually all of the details of the non-sky portion of the visual field would be diminished.

This prejudice of viewing landscapes is carried over into viewing representations of landscapes. It is also, possibly, the foundation for the relatively sustained temporal nature of small scale receptive fields. By sustaining the illumination informa-

tion contained in small scale fields, the visual system does not allow the the brightness information projected in the large scale sky to overwhelm the entire scene. In other words we actually tend to ignore the sky in terms of brightness and chromaticity because it covers so large and expanse, frustrating our normal process of fixation on a field of small visual angle and because it would skew the perception of objects in the landscape, objects that are frankly much more important to us, as potential sources of food and in the avoidance of danger. Most importantly Marr's argument, in favor of the spatial-frequency tuning of visual information at a very early stage of retinal image processing, physically supports the presumption of a layering of visual impressions.

A psychological consideration of color

Color studies are such a vast domain within perceptual psychology that I need to divide the psychological consideration of Grainstacks into three parts in order to make three different points. The first response to Grainstacks will be by a psychophysicist speaking from the point of view of trichromatic theory. The second response will be on the basis of opponent processing and the third interpretation will be offered from the point of view of experimental psychology. Trichromatic theory will be used to discus the brightness contrast, color constancy, simultaneous and successive contrast. Opponent processing theory will be used to establish the nature of chromatic adaptation. The point of view of a perceptual psychologist will be adopted

to discuss one hypothesis concerning the cortical processing of visual information.

Trichromatic Theory[10]

Trichromatic color theory is the theory of color as processed in the retina with its three primary color receptors. It is particularly difficult to use trichromatic theory to interpret Grainstacks (End of Summer) because Color psychophysics generally studies what are called "unrelated colors". Unrelated colors are isolated patches of color in a visual field. Psychophysics adopts this approach so that the myriad variables that affect color can be studied in isolation. This is part and parcel of traditional scientific method. In the case of color, one trades analytic accuracy and logical inferential chains for being able to say anything definitive about color, or even about, for instance, scarlet, unless it is carefully qualified by a description of the experimental set up, measured values for the quantity of illumination, its spectral composition, the reflectance (or transmittance) factor of the body illuminated, the sensitivity curves of the standard observer and so on. This trade off is a legitimate exchange since it has elucidated so many phenomena that otherwise would remain mysterious, although it makes speculating on the effects of Grainstacks difficult since the conditions of observation are not readily specifiable in psychophysical terms. The precedent for stepping outside of the psychophysical paradigm to reflect on painting was provided by von Helmholtz who applied the insights provided by an

empirical descriptive vocabulary (brightness, hue, saturation) to painting.

What should be clear from the exposition of brightness, hue, saturation (in chapter 3) and of luminance, dominant wavelength, purity and chromaticity (in chapter 4) is that the dimensions of color in psychophysics are related in such a way that a change in any one of the variables is mirrored in a change in the others. Diminish luminosity and the chromaticity shifts. This is particularly true of yellows--where a chrome yellow appears as an ochre brown under low illumination--but it is true of other colors as well. In the same way purity is affected by a change in luminosity. Consider red and blue. Under conditions of normal to high luminosity red seems more pure than does blue. Observe the same colors under dim lighting conditions and the red seems less pure and the blue relatively more so.

In terms of related colors--two chromatic colors juxtaposed in a visual field--the perception of dominant wavelength or chromaticity shifts differently according to the colors juxtaposed. A maroon next to a scarlet makes the maroon seem more violet and the scarlet seem more yellow, a shift in the appearance of the dominant wavelength. Violet next to a yellow makes the yellow appear more yellow (greater chromaticity) and visa versa. These shifts in the impression of the dimensions of color occur at the level of sensation so it is strictly accurate to say that the juxtaposition of yellow and violet elicits a hue shift, since the dominant wavelength of the light reflected off the target color does not change, only the subjective impression

of hue. It is just this difference between the objective (physically measurable) conditions of dominant wavelength and the subjective impression of hue difference, that constitutes the domain of visual psychophysics. Psychophysics is, in this context, the study of contrast, and theoretically there are as many different kinds of contrast as there are relationships among the attributes of sensation. Although, von Helmholtz in his essay "The Relation of Optics to Painting," explicitly treats only brightness contrast and color contrast. Following his lead a psychophysical interpretation of Grainstacks has the most to tell us about these phenomena.

Brightness contrast renders the ratio of brightnesses in a scene as opposed to the absolute magnitude of luminosity. The ratio of absolute brightness between the sky and the shaded side of the haystacks, for instance, is impossible to transcribe using paints since the reflectance of the surface of the painting is limited by the intensity of the light falling on the paint. There is simply no way the light reflected off of the upper right quadrant of the painted surface could approach the absolute brightness of sunlight, even diffused sunlight. Therefore the rendering of brightness in the landscape, which cannot be transcribed, must be translated; and as long as the ratio of lightness and darkness in the representation is rendered approximately consistent with the much greater ratio of lightness and darkness in the scene, it is possible for the painting to mimic the landscape in the eye of an observing subject. The question of color contrast presents a distinct and somewhat

contradictory situation.

Color contrasts allows forms that would not be distinguishable according to brightness contrasts, to stand out as distinct shapes. This is particularly evident in the smaller grainstack. If it were not rendered as an orangish brown it would not stand out in front of the middle distance trees, rendered in steely blue green, and the far distance hills, rendered in grayish violet (all of which are approximately of the same value). As it is Monet has blurred the distinction between the hills and the trees so that the viewer is not exactly sure what line separates the middle distance from the far distance. The same condition would occur (in terms of value) if the shadow side of the small grainstack abutted the trees without any highlights. Without a hue contrast (and without the hint of a highlight on the smaller stack) the grainstack would be indistinguishable from the tree line, would be indistinguishable from the distant hills. Color contrast, therefore; creates differences that supplement brightness contrast and greatly extend the range of contrasts that distinguish forms in a landscape. In other words, learning to render colors in a given scene is partially about unlearning the mechanism that triggers brightness and color constancy while, at the same time, figuring out how to clue the viewer's visual system to the global conditions of the lighting.

In terms of color contrast, painting is still a translation of the scene and not a transcription. Transcribing the local color of the smaller grainstack an inexperienced painter might render it with all the colors evident in the larger stack and

with colors just as pronounced. Monet does not do this. He desaturated the colors used in the large grainstack in the smaller one and renders it with coarser brush strokes--in effect conveying less detail--less detail in the color and less detail in the texture of the form. This is the way Monet translates the color contrasts in the landscape to support the impression of depth.

There is virtually no difference in the brightness contrast between the smaller stack, the middle distance and the far hill but there is a color contrast that clues the viewer the smaller grainstack is further away and not just physically smaller than the large grainstack. Yet the smaller stack is distinct from its immediate background, even though there is no brightness contrast, due partially to a highlight, due partially to a contrast in color. Most importantly the color contrast is translated relative its immediate vicinity and relative to a similar form spatially not contiguous with the smaller shape. These contrasts rely on a factors other than color and brightness (such as detail frequency and occluding shapes) in order to complete the illusion; but color in Monet's work plays an especially important role since he uses it as a prime descriptor of shape rather than, as so may of his predecessors did, relying primarily on brightness contrast to establish the relationships among forms in the visual field.

Two other contrast effects remain to be described in terms of trichromatic theory. I am referring to "simultaneous" and "successive" contrast. Simultaneous contrast is the tendency of juxtaposed colors to alter the perception of hue in each of the

adjacent colors. Successive contrast is a product of a roaming eye, the tendency of successive fixations to overlay prior color sensations on current color sensations. Both the phenomena are dependent upon the physchophysical process called induction. Induction describes how a sensation of color may be initiated without a presentation of colored stimulus. In simultaneous contrast, cones, which in the retina are linked together laterally, create or "induce" another color in neighboring sensors. In successive contrast, a fixation on one color "fatigues" or diminishes the effective retinal coding of the color presented. As one stares at the color it fades as the sensors become weakened from prolonged exposure. Shifting fixation to a white piece of paper, one experiences an induced color, complementary to the color first observed. Shifting fixation to another target color will change the impression of the color of the new target in a manner comparable to adding light of a complementary color from the first fixation to the color of the second fixation. Adding the complement of yellow (violet) to blue makes the blue seem bluer. Adding the complement of violet (yellow) to red makes the red seem more orange. The hue shift depends on the location of the colors on the spectrum locus and the point is, the hue shifts are predictable, rigorously so in psychophysics approximately so in painting.

Successive contrast in the scene Monet viewed would have contributed a great deal to his impressions of color in the landscape he was painting. In the scene, a prior fixation on the sky overlaid on the hills just below the horizon would make the

hills seem lighter, less saturated and of lower chromaticity. Fixating on the portion of the sky Monet rendered in yellow overlaid on the shadow of the large grainstack would shift the hue of that shadow even more towards the blue, making it appear more saturated and of higher chromaticity. Successive contrast is an important factor in the perception of the landscape because the brightness contrasts are so extreme that the colors are almost immediately induced and have a pronounced effect on successively perceived colors.

The effect of successive contrast in viewing the painting, on the other hand, is almost negligible. An observer would have to stare fixedly at the yellow portion of the canvas for several seconds in order to induce a complimentary hue and even then the induced color would not be nearly as strong as under natural viewing conditions. Therefore, simultaneous contrast, which functions in principle in just the same way in the painting as it does in the scene, must be used to mimic nearly all the effects of successive contrast in the landscape relative to the painting. This heightening of simultaneous contrast using paint is, of course, the technique that distinguishes Impressionism from its painterly predecessors and the point is that successive contrast in a scene is rendered in a painting by means of a heightened simultaneous contrast. The way successive contrast heightens an impression of the landscape is not well accounted for in trichromatic theory. In order to understand quantitively how complementary colors are mutually enhancing, one must look to the theory of opponent color processing.

Opponent Processing Color Theory[11]

Opponent processing was Ewald Hering's challenge to von Helmholtz' formulation of trichromatic processing. It assumes that color perception is describable in terms of the relative weighting of white/black, red/green and yellow/blue and accounted for the subjective difference between unitary colors such as yellow and compound colors such as purple. Jameson and Hurvich revived the ideas of opponent processing in a series of four articles in the Journal of the Optical Society of America in 1956. They revived Hering's theory by showing that the terms of trichromatic processing could be mathematically transformed into the terms of opponent processing. Having proved the identity of trichromatic and opponent processing theories they proceeded to develop a means for quantifying chromatic adaptation.

Chromatic adaptation is based on the same basic idea as brightness adaptation, but it applies to the attribute hue. In brightness adaptation the logarithm of luminance is used as a measure of illumination that restricts the overall brightness range to which the eye is potentially sensitive (which is overall a ratio in the neighborhood of four million to one) to some local range that is tuned to the scene at hand (fig.68). Chromatic adaptation, by analogy, is what happens when the visual system is asked to sense hues under different color temperatures of illumination or, more importantly, under colored illumination (as distinguished from full spectrum sunlight). Trichromatic theory treats chromatic adaptation as a special case of

successive contrast.

Given that brightness adaptation and chromatic adaptation are conceptually analogous phenomena the physiology that underlies them are actually quite different. Brightness adaptation was first explored because it was noticed that humans do not perceive much (or any) color at night. This lead to the discovery that there are two distinct sets of sensors for the sensation of light, two retinas, as it were. Under low luminance conditions a retina composed of rods samples the visual array. Under normal (higher) luminance conditions an entirely different retina of cones senses the visual array (figs.69,70). This is called the duplicity theory and the adaptation states associated with these conditions are scotopic and photopic (respectively).

Where brightness adaptation uses the duplicity theory as a foundation upon which to establish local brightness adjustments within a general photopic range, chromatic adaptation is not founded upon such a neat difference between systems of sensors. Chromatic adaptation is strictly a phenomenon of photopic conditions since only cones sense color differences. Von Helmholtz was aware of chromatic adaptation and postulated that it could be accounted for when light input to the principal receptors is attenuated by some factor. Von Helmholtz' conclusion implies that the attenuation takes place at a neural stage where the response of the receptors to the light input is still linearly related. Johannes von Kries (1853-1928) expanded von Helmholtz' basic formulation in his coefficient law, which postulated a separate gain mechanism in each system of cone receptors. Von

Kries' coefficient law assumes that dim and bright stimuli would be attenuated in the same proportion; but it turns out that experimental evidence does not bear out a proportional attenuation under chromatic adaptation. In fact color contrast is at a maximum when brightness contrast is at a minimum (Kirshmann's third law) so the coefficient law, based on the proportionality of attenuation under dim and bright illumination does not work as formulated. In other words chromatic response is not linearly related to the sensation of brightness and chromatic adaptation needed to be quantified by another, non-linear neural process. Hurvich and Jameson's revival of Hering's opponent process provides just such an explanation.

Opponent processing posits that incident light is processed by four selective photosensitive units, blue, green, yellow and red (B, G, Y, R). Under conditions of neutral stimulus or the full spectral distribution of "white" light (photopic conditions) the functions of the tristimulus values can be linearly expressed as functions of the receptors B, G, Y, R. The yellow-blue (y-b) opponent process is defined as a constant (k1) times the yellow absorbed unit minus the blue absorbed unit [y-b=k2(Y-B)]. Likewise the red green (r-g) opponent process is defined as a constant (k2) times the red absorbed unit minus the green absorbed unit. Given a state of chromatic adaptation the basic response by a photosensitive retinal sensor remains invariant but the opponent process changes form, relative to balanced adaptation. Responsiveness under chromatic adaptation is modified in inverse proportion to excitations produced by the adapting stim-

ulus. This approach provides a non-linear transformation of basic trichromatic information under conditions of chromatic adaptation. In other words, blue adaptation increases the sensitivity of the system to yellow and visa versa. Likewise red adaptation increases the sensitivity of the system to green (and visa versa).

So far Jameson and Hurvich have asserted (1) a system of four receptors, (2) the identity of the receptors with the receptors of the trichromatic system, (3) the opponent relationship between pairs of receptors, and (4) the general behavior of the system. In order to define the quantitative relationship amongst opponent pairs they have only to establish a baseline condition of neutral adaptation and a theoretical limit for complete adaptation. Adaptation, it is assumed, is the product of the photosensitive units (B,G,Y,R) and a coefficient that is the ratio of balanced adaptation and the excitation value of non-neutral stimulus.

Balanced adaptation is a condition where the y-b channel favors neither yellow nor blue, which is, by definition, adaptation to neutral illumination (ditto r-g). The coefficient that yields complete adaptation is assumed to be given by the von Kries proportionality rule. We can therefore determine the percentage of adaptation, given two limiting cases by observing the unitary hues (blue at 475mu, green at 500mu, yellow at 580mu, and red as a combination of 440mu and 670mu lights) under conditions of neutral adaptation and extrapolating the theoretical maximum using the von Kries coefficient, the percentage of

partial adaptation can then be plotted on a graph where the abscissa, called chromatic valence, is in arbitrary units given by the change from neutral to complete adaptation and the ordinate is wavelength (in mu). See figures 71 to 76 for graphs that quantify states of adaptation in this way. A number of very interesting results are presented in these graphs.

First and foremost is the tendency of chromatic adaptation to magnify the chromatic response of the visual system to the color opponent to the adapting light and depress the response of the system to color of the same hue, relative to neutral adaptation.[12] In blue adaptation a blue object in the visual field would appear washed out where a yellow would appear more yellow. Given yellow adaptation the reverse is true. Under green adaptation greens are diminished and reds are intensified and given adaptation to a red illumination, reds are comparatively dull and greens are relatively vivid. Given b-y adaptations the g-r chromatic valence does not change relative to neutral adaptation and visa versa. It is important to note that according to this model small deviations in the excitation curves of experimental subjects from the standard observer are projected as large changes in the form and magnitude of the chromatic response.

Other interesting results are considered relative to the various states of adaptation. Under yellow and blue adaptations the blue response is more stable than the yellow and the red response remains unchanged, but, the green locus shifts, under yellow adaptation towards the shorter (blue) wavelengths and under blue adaptation towards the longer (red) wavelengths. In

green adaptation the red and green maxima are displaced towards midspectrum while the blue locus shifts towards the long wavelengths and the yellow shifts towards the short wavelengths. Given red adaptation the opposite occurs, i.e. red and green shift towards the outside of the spectrum, blue is displaced towards the short wavelengths and yellow is shifted towards the long wavelengths. It is especially important to note that, in this model, it is possible for both opponent pairs to be affected (called a "binary hue response").

Further ramifications of this model are discussed in terms of the interaction of adaptation with brightness, saturation, and hue. The opponent processing model accounts for the difference between the effects of brightness adaptation and chromatic adaptation by asserting, in brightness adaptation, that the white-black (w-bl) system of discrimination is related to both depletion and regeneration of the photosensitive receptors while in chromatic adaptation the system responds only to depletions; blue adaptation does not regenerate blue sensors, it only diminishes them. The opponent processing model also accounts for the way chromatic adaptation affects luminosity. Luminosity shifts, due to chromatic adaptation, occur in experiment where the theory predicts they should. It also implies that for complete adaptation the adapting stimulus will itself, appear achromatic. This makes sense because when chromatic illumination, of the same wavelengths as the wavelengths of light reflected from an object (illuminated by full spectrum, achromatic light), are substituted for the achromatic illumination, the object appears

of indeterminate hue (bright only, without color).

In terms of saturation, the opponent process model is perfectly consistent with the experimental evidence collected on the nature of successive and simultaneous contrast, (called temporal and spatial contrast effects in Jameson and Hurvich). Fixing the central field of vision on a red object induces a red adaptation that affects the saturation of green in a successive fixation. At the same time the magnitude of the enhancement of two spatially contiguous colored patches can also be predicted using this adaptation model.

In terms of hue and adaptation the opponent model necessarily considers only incomplete states of adaptation. This restriction accords with the dictates of common sense. The experimental requirement for a state of complete adaptation would present a test field of only one color. Any attempt to introduce another color would disturb complete adaptation and therefore the subject could not be in a state of complete adaptation. The role of the notion of complete adaptation is; therefor, used only as a way to establish a theoretical maxima in order to calibrate the scale of chromatic valence.

The relationship between hue and adaptation shows how the perception of unitary hues are shifted under different states of adaptation. (I will offer only one example of one case, under one type of adaptation but rest assured that the variety of conditions could proliferate examples.) Given blue adaptation, an almost unitary green appears yellow-green, neutral adapted. Since hues are displaced under different conditions of adaptat-

ion, the opponent process model allows the specification of complimentary wavelengths under different types of adaptation which are correlated to different illuminations. Viewing green grass under blue illumination can be described as what happens to green given partial blue adaptation. In short, given we are always discussing incomplete adaptation, the perception of hue is predictably shifted depending on the state of adaptation.

It is, of course, impossible to precisely quantify the displacement of hue in Grainstacks since we can have no data about the spectral distribution of hues in the Giverny landscape on the days in 1891 Monet worked on this canvas; but, we can, in a general way, discuss the color shifts Monet rendered. From the shadows we know the sun was low in the sky, enlivening the atmosphere with a progressively stronger yellow glow as the eyes track towards the sun, setting just outside of the frame. We may also surmise that the scattered light from the zenith of the sky was pervasive, strong enough to fill the shadows with a blue tonality. We can therefor conclude that the adaptation conditions in one circumstance favored yellow and in another way favored blue. Opponent theory assumes that these colors would cancel each other at the largest scale of spatial resolution in the scene, and indeed this seems to be the case. Many of the colors in the distance can be accounted for by reference to diffusion, scattering, and atmospheric perspective (diminishing brightness) with very little or no recourse to states of adaptation. At smaller scales of spatial resolution, however, we may assume the painter's eye freely roamed and, that, in the percep-

tion and the rendering of detail, opponent mechanisms were at work.

The influence of yellow adaptation would be strongest as Monet considered the sky in the direction of the setting sun and the rays of light tinged yellow as they spill over the highlights of the landscape. Under these conditions, relative to neutral adaptation, the foreground oranges would appear redder and the reds would appear bluer. Actually there is no way to even speculate on what might have appeared orange in the original scene; but, a bluish cast is evident in the reds that appear on the shadowed side of the grainstacks. These reds are rosy, tinged with blue both because the fill light is of a blue cast and because adaptation pushed them in that direction. Furthermore greens will seem yellower and if we assume that there is some green in the field (as Monet indicates there is in the lower right hand corner of the canvas) it makes sense that he would render these colors as a light yellowish green. The greens in sunlight are yellower, again for two reasons, one because the light illuminating them has a yellow cast and because the adaptation mechanisms pushes unique green yellower.

Given yellow adaptation, green with a little bit of blue is going to appear bluer and blue-green will appear greener. In this case green that appears in the shadow portion of the grainstack, which is green with an overlay of blue (fill from the sky) or blue (the color of the shadow) with a bit of green (from the low ground cover) is rendered in emeralds and bluegreens as the model suggests. We might account for the violets

in the shadow of the grainstack by assuming that straw yellow (what is left of the harvested grain stalks) is desaturated by the state of adaptation so that the blue fill dominates, rendered as violet in order to provide a color contrast from the other blues in the shadow.

What yellow adaptation does not account for, and indeed is a contraindication in the landscape as I am describing it, is the intensity of the yellows. To account for this I assume that, whereas the eye cannot be adapted simultaneously to blue and to yellow, Monet would have been, during the hours he was painting, alternately adapted to blue then yellow. As he noted colors in the landscape and as he picked pigments in which to render them, he picked colors that made for a coloristically balanced painting. Since he must render successive contrasts in terms of simultaneous contrasts he picked an overall contrast for the painting in terms of the complimentary pair yellow blue and then he used his acute and practiced color vision to develop local contrasts suggested by the successive fixations he experienced in his adapted state. In the case of blue adaptation the straw stalks of the harvested field are rendered in an intense chrome yellow right at the boundary of the blue shadows and a paler lemon yellow further away from the mutually enhancing blues; but, really, this interpretation does not even get at the most important implication of the painting, considered from the point of view of adaptation.

There must be some element in the painting that clues the viewer to the adaptation context of the representation. I think

that this element is the facade of the barn at the center of the painting. If the viewer norms the color of this triangle to white then the tinge of blue that it displays under scrutiny actually clues the visual system to perform as if it were blue adapted. The general affect of this shift would be to spike the impression of yellow and depress the impression of blue. This accounts for the overwhelming impression of the strength of yellow in the image, when in fact, compositionally, the yellows below the horizon are rather spotty, clearly subordinate to the blues of the shadow thrown by the large grainstack. Since the visual system recovers quickly from the induced hue shift a subsequent inspection of the blue and violet portions of the painting would hardly depress these colors, and the viewer would be left with the impression of an intensely yellow and blue painting, even though we cannot be simultaneously adapted to both these colors. But even this interpretation of Monet's translation of the scene does not quite capture what I think is most extraordinary.

What I am referring to is that Monet, if he picked his colors under the same adaptive influence in which he viewed the scene, would end up with a painting that, under gallery viewing conditions, would not come across as a twilight scene. In other words Monet had to be working simultaneously in two different color registers in order to create a representation that conveyed the sense of the landscape at sunset, when the canvas was viewed under more typical lighting conditions. What constitutes Monet's ability to reconstruct the scene using information from

two different color registers and the viewer's ability to reconstruct the reconstruction, is the subject of the next chapter.
I will be develop this observation with reference to perspective and, for lack of a better term, the next to the last interpretation of Grainstacks will be developed under the heading "experimental psychology."

Experimental Psychology

This portion of chapter five follows closely the argument presented in Michael Kubovy's The Psychology of Perspective and Renaissance Art (1986). I include it under the sub-heading "experimental psychology" because Kubovy's goal is to clarify the use of perspective in Renaissance painting 'using the analytic tools of experimental psychology' (p.viii). His study examines the role of shifting egocenters in Renaissance painting.

The concept of a shifting egocenter is the product of a 'deliberately induced a discrepancy between the spectator's actual point of view and the point of view from which the scene is felt to be viewed' (p.16) which results in a vivid perceptual experience. Given the ability of the human perceptual system to reconstruct perspective representations Kubovy must establish that viewers can shift their point of view without changing their physical location, what he calls the robustness of perspective. He argues persuasively that in order for the viewer to be able to perceive the virtual space of the representation as invariant without regard to the observer's vantage point, the observer must simultaneously judge the orientation of the sur-

face of the representation relative to her own point of view. Given this information normal viewers can correctly reconstruct perspective representations, accurately interpreting parallelism and orthogonality in the picture as if it were viewed from the center of projection[13](fig.77).

Given the robustness of perspective Kubovy uses the 'notion of a spatially localized, visual egocenter that does not coincide with either eye' (the so-called "cyclopean eye") to analyze the effect of Leonardo's Last Supper. In order to physically bring a viewer's vantage point into correspondence with the center of projection of the fresco, the viewer's vantage would have to be fifteen feet one inch off of the existing floor. Since there is no way to assume this view in the refectory as it was constructed, Kubovy argues that Leonardo purposely made the projective center of the painting inaccessible. "[T]he viewer infers the location of the center of projection and reconstructs the scene as it would be seen from that point" (p.103). This act constitutes a displacement of the viewer's visual egocenter and draws on the information available in two frames of reference, the frame of the virtual space of the representation and the frame of the surface of Leonardo's fresco.

If displacement were only a shift of viewers' egocenters among virtual and actual points of view it would rate as another kind of visual scaling, an operation we naively perform when the situation demands and not as a release of perceptual energy that signals a vivid experience. But, displacement is more than just another kind of scaling. Displacement simultaneously shifts the

egocenter and makes the observer aware of the egocenter shift, by calling attention to the act of perception. This is what Kubovy calls a metaperceptual experience and the means Leonardo uses to encourage the viewer to attend to the act of perception pertains to the discrepancy between the imaginary space of the painting and the real space of the refectory (not just the surface of the fresco).

> Because there is a suggestion of continuity between the real and the virtual architecture, the inconsistency between them "pushes" you away from the low vantage point to which your body confines you, and "pulls" you up toward the center of projection, which resolves the tension. At the same time, the inconsistency helps you adopt a noncorrective way of looking at the fresco, one in which the you can pay attention to the rather jarring discrepancies between the virtual and real architecture. In this respect, Leonardo created a "difficult" work of art, one that forces you to engage in mental work to overcome the obstacles Leonardo has placed in your way to achieving an illusion of depth via perspective. (p.145)

Kubovy's account shows how displacement, induced by a perspective representation, engages our basic perceptual competencies

One conclusion of this line of reasoning that Kubovy discusses in passing, is worth mentioning. He notes that "we cannot arbitrarily change the way we perceive optical information, nor can we arbitrarily change our motor responses to it..." (p.165). As an elaboration of this idea in the context of the interpretation of painting, I would note that in the collaboration of artwork and observer, artists are forced to design their works in accord with our perceptual system's neurological competencies. The competencies are tuned to perceiving the real qualities of

real objects in a real world. Interpretations, on the other hand, are not necessarily constrained in the same manner. Once an observer experiences displacement, and the coincident release of perceptual energy, she may attribute it to spiritual insight, vivid understanding, or too much wine at lunch; but, the interpretation is not necessarily limited by the motor response.

Considering Grainstacks (End of Summer) in the context of displacement, I have already argued that the color context of the painting exists in two registers, the register of twilight color conditions which the painting evokes and the register of photopic adaptation in which the painting is viewed. Since there is no way that the painting, with its limited brightness and color ranges, duplicates the experience of vivid color at the gloaming, it must invite the viewer to suspend disbelief and shift a colored visual egocenter, or "color locus," so that we see the painting as if it were a landscape in twilight. But, simultaneous perception in two registers is only a necessarily condition of displacement and not a sufficient condition. In order for displacement to occur some other circumstance in the act of perceiving the painting must set up an inconsistency that "pushes" one away from the photopic vantage point defined by the viewing conditions, and "pulls" one toward the virtual lighting conditions suggested in the painting, which resolves the tension.

I think the inconsistency Monet exploits is a tension between the visual system's tendency to interpret the scene monochromatically or chromatically. David Marr established that at

a primitive level of visual processing, even before the object of consideration is located in a viewer centered coordinate frame, we derive information from the visual array using brightness contrast. It is possible to read Monet's painting in terms of brightness. The brightness contrast between the lighter and darker portions of the painting gives a basically accurate interpretation of the shapes in the landscape; but, the general chromatic key of the painting is so high, particularly in the foreground, that the viewer is encouraged to reconsider the accuracy of the derivation of shape from brightness. Shadows are not typically bright blue, green and violet. Highlights are not typically chrome yellow, lemon yellow and rose orange. This tension, between our expectation of the color of shadows (dark and basically neutral with maybe a hint of subtle color) and the color of the shapes that in every other regard are playing the role of shadows, is the tension that facilitates displacement.
My point is not that anyone looking at the painting, always enjoys a metaperceptual experience. It is just that when we do it is facilitated by two sets of unresolved tensions; one between the interpretation of twilight lighting conditions and photopic lighting conditions and the other between reading shape (and depth) in terms of brightness contrast or in terms of color.
Due to the way Monet handles color the viewer is encouraged to resolve these tensions by shifting a color locus (color "visual egocenter") so that the landscape is perceived as painted in the vivid light of a setting sun.

Two obvious questions remain. On what basis can I hypothes-

ize a locus of color perceptions that facilitates shifts between virtual and actual conditions of light and color? And what is a color locus? I feel confident proposing a color locus because so many perceptual affects are linked to the sensation of light and dark and have an analogous affect linked to color. This coincidence may be an artifact of the way psychologists construct models, but it seems to work much better than the word "coincidence" suggests. Brightness contrast is analogous to color contrast. Brightness constancy is analogous to color constancy. Brightness adaptation is analogous to chromatic adaptation. The analogy between brightness phenomena and chromatic phenomena is just that, an analogy not a mirroring, because system performance is always subtly different in the processing of light and in the processing of color; but the analogy holds and I think it holds for the cyclopean eye as well.

If our perception of depth is reconstructed as Marr suggests, out of the sensation of brightness differences, then it is logical to assert that there is a perception of depth that could be reconstructed, or at least would support the reconstruction of depth from color clues. If the perception of depth is reconstructed first in a viewer centered coordinate frame (2-1/2 dimensional sketch), later in an object centered coordinate frame (3-d representation), and later still from information gleaned from the interaction of a viewer centered frame and object centered frame (Kubovy's argument expresses in Marr's terminology) then the perception of depth from color clues could plausibly follow the same progression, including the ability to

compare virtual and real color palettes and shift between them. I call this perceptual competence "shifting the color locus" and I think of it relative to an analogous competence in the sensation of brightness.

I named the color locus so as to evoke the spectrum locus. The color locus includes all the colors of the spectrum locus as well as colors that, in the chromaticity diagram, are called "imaginary colors." Imaginary colors are colors which in von Helmholtz' words "the sensation of the purest red light is not the sensation of the purest red conceivable" (p.136). Chromatic adaptation, simultaneous and successive contrast quantify these phenomena and one way to think of the color locus is as the spectrum locus only larger; but in another way the color locus is different from the spectrum locus. The spectrum locus is constructed on the basis of the consideration of isolated colors and even though this model includes in the definition of any given color, factors for the color temperature of the illumination and the sensitivity of the eye, these colors still exist in isolation. Somehow the color locus must account for (1) related colors and (2) groups of colors in palettes and (3) arrays of colored palettes.

The necessity of including related colors in the color locus is implicit in the inclusion of imaginary colors, since imaginary colors are created through the interaction of two or more colors as states of adaptation. Including groups of colors in the definition of the color locus (what I shall call color "palettes" after the painter's terminology)(fig.78) is important

because whereas, almost all palettes display lead colors or dominate chromaticities, one shifts the perception of the lead color (and the overall palette) depending on how one accents it. Therefore a more sophisticated organization of the color locus must include some memory of palettes of colors and by extension arrays of palettes of colors. An array of a palette of colors might be thought of as a constellation of conditions under which one perceives a given palette in a given landscape. It assumes that the palette of colors of all of Monet's late summer Grainstack paintings are related by the colors given in the scene and that those colors change, in principle, in predictable ways under different conditions. Furthermore, it assumes humans can remember and compare palettes that vary from one local to another.

In other words, parts of Missouri in autumn and parts of Connecticut in the fall are topographically and scenically very similar. Rolling hills, comparable deciduous trees, hand made low stone walls; all of these features are common to both places yet the places look and feel different. The difference, I assert, is in the quality of light illuminating the respective scenes and the color palettes these quality of lights promote. Some mechanism allows us to perceive, remember and compare these landscapes at the level of their respective color palettes and this mechanism is part of the function of the color locus.

In conclusion, building on an analogy to Marr's model of visual processing, I use Kubovy's exposition of shifting egocenters to establish a hypothetical color locus in color perception. The color locus is what allows Monet to function simul-

taneously in two different color registers, translating the light context of the landscape into a representation. The color locus also is what allows the viewer to correctly decode light conditions from color juxtapositions. The shifting of the color locus, furthermore, creates the possibility of displacement, which involves a release of perceptual energy to which the mind ascribes meaning. The conditions which promote this release of perceptual energy are constrained by existing neurological competencies but the meaning attached to them are not necessarily constrained in the same way, being a matter of interpretation in a linguistic frame of reference.

A painterly consideration of Grainstacks

The difficulties presented by reconstructing the colors Monet used in Grainstacks (End of Summer) are enormous and, consequently, so is the potential for error. John House in his study Monet: Nature into Art (1986) identifies four major problems: "the material condition of paintings, the conditions in which they are seen, the limitations of color reproduction, and the absence of an objective and sophisticated language for describing color" (p.109). Nonetheless I will attempt to identify the pigments Monet used, bearing in mind the following possible sources for error.

The material conditions of Monet's paintings varies, depending most obviously on whether or not they were varnished. Art historians believe Monet never varnished his own paintings but many of them were varnished, especially in the early days,

by his dealer(s). Varnish changes color over time and this can radically change the tonality of a painting. Just how much it changes the colors is remarkable, as anyone who has ever seen a freshly cleaned favorite painting well knows[14]. Furthermore some pigments actually change color upon exposure to air. This has been known since, at least, the Renaissance. Accounts exist that note the transformation of white into black in frescoes by Cimabue (the "Crucifixion" in the North transept of the Upper Church of San Francesco at Assissi). The reality is that the colors of paintings change over time and although, some of the changes are well known to restorers, we may only guess at others.

The conditions under which pigments are seen also alter the perception of colors in ways related to the color temperature of illumination and the color context of the display. Monet painted the Grainstack series outdoors, putting the finishing touches on the paintings in his studio. In both instances he was painting in natural sunlight. There is no way to extrapolate the perception of colors from artificial illumination to full spectrum sunlight (or diffuse northern exposure) by simply looking at the canvas.

The nineteenth century conventions of the display of painting in galleries should also be noted. In the nineteenth century gallery walls tended to be darker, and of warmer tonality, than are typical today. Therefore, Monet anticipated that his paintings would have been among the lightest things in an exhibition space. The luminosity his scenic translations depended upon is

severely diminished when the canvases are displayed on the light, or even white walls, still favored in many contemporary galleries.

The limitations of the color reproduction of paintings opened this thesis and it should be obvious by now that the subtlety of observation I seek simply cannot be captured in any kind of color reproduction. There is no way, using "process" colors in four color printing, that ultramarine blue can be anything but approximated by the optical mixture of cyan, yellow and black dots of semi-transparent ink on white paper. This does not mean that color reproductions are worthless, only misleading when they are used as the sole source of color information. If one is previously familiar with the painting and generally familiar with the color of pigments, I assume one may reconstruct the palette of paintings using the reproduction as a surrogate.

Even though the reconstruction of the Monet's palette is suspect[15] the precision of color perception versus the ambiguity of color language actually works in favor of a reconstruction from a reproduction. Pigment colors are not infinitely variable. They are, in the terms of visual psychophysics, different chromaticities (combinations of hue and brightness) and since oil pigments are formulated with regard to their chromatic permanence, not just any formulation will do. Pigments must be relatively stable and they must be close to fully saturated, since the mixture of pigments diminishes saturation in the resulting color. Given these two requirements pigment colors like Monet

may have used on his palette, can be inferred since they gravitate towards certain specific chromaticities. These specific chromaticities are different enough so that the root pigment may be inferred, even from a colored approximation.

The near impossibility of communicating the nuances of colors in language is blatant but it does not follow that color language can (or should) be restricted to the terms red, yellow, green, blue, pink, orange, purple and brown or even brightness, hue, and saturation. Up to this point the interpretation of Grainstacks has generally not required a more specific vocabulary and the effect of Monet's painting is dependent on a finer, but still generic, color terminology. The more precise terminology I will use is supported by what documentary evidence exists as to the precise pigments Monet used (in a letter Monet wrote in 1888 and in records from Moisse, Monet's color merchant).

Are pigment names a perfect color description language? No. Do pigment names express differences in chromaticity difficult to communicate any other way? Yes. Therefore; I will attempt to name Monet's pigments, using names that are current in contemporary color charts with the understanding that one of Monet's green pigments may not have been called "viridian" but that the effect of some combination of hue brightness and saturation one brushstroke conveys is in the family of what is currently called a viridian green.

Cautions and caveats aside, the number of distinct pigments in Grainstacks is surprisingly large. There are probably two

yellows, cadmium yellow pale and lemon yellow; one orange, deep cadmium yellow; one red, rose madder; two greens, viridian and emerald; two blues, cobalt and cobalt violet; lead white and burnt sienna[16] (fig.79). I shall try to analyze the painting in terms of layout of these colors.

Monet uses almost all of the pigments on his palette in the grainstacks; burnt sienna, rose madder, cadmium yellow deep, cadmium yellow pale, cobalt and lead white. In the large grain-stack the darkest color in the canvas occurs, near the peak of the stack. Although I do not recall taking notice of the precise tonality of the pigment in my inspection of the original canvas, Monet is well known for having giving up the use of black, therefore; I surmise this hint of a very dark color is burnt sienna, used at full strength. The remaining brown tonalities of the grainstacks are a built up of the mixture of burnt sienna; burnt sienna and lead white, burnt sienna and rose madder, burnt sienna and cadmium yellow deep, and burnt sienna and viridian. The dark green gestures to the right of the center of the large stack are viridian mixed with burnt sienna, on top of a mixture of burnt sienna, white and, occasionally, a little rose madder. On the left side of the grainstack the rose madder shows, tinted with lead white and burnt sienna. The highlight on both grain-stacks seems to be deep cadmium (orange) with white dry brushed on top. There is even a slash of cobalt evident in the large stack on the right side towards the top. Whether Monet mixed the cobalt and burnt sienna on his palette I cannot ascertain. In the clumps of straw on the ground surrounding the large stack

and in the lower portion of the small stack Monet seems to have used a mixture of deep cadmium yellow and burnt sienna, in which patches of an almost fully saturated deep cadmium are evident.

The grainstacks almost exhaust Monet's use of the burnt sienna, and where it occurs again is instructive for the coloristic unity of the painting. Where he uses the burnt sienna again it is not insistently brown; it is usually disguised by mixture with another pigment. Burnt sienna desaturated with white is subtly worked into the middle distance to the right of the barn, used as a base coat in the ridge of the far hill (overpainted with pale cadmium to blur the distinction between sky and horizon), combined with viridian in the shadow of the large tree, dulled with white in a tree like shape to the right of the large grainstack and, in the foreground combined with rose madder in Monet's signature. In other words Monet does not switch to a different pigment to render the local colors in these parts of the scene so that they are "correctly" represented, but instead recycles the lead color of the grainstacks, underscoring the coloristic unity of the composition.

Monet's use of cobalt and cobalt violet similarly supports the coloristic unity of the painting through their arrangement. The cobalt violet is used, desaturated, for distant hills on the left, (probably) picked up with a little rose madder in the roof of the barn, swirled in with viridian in the middle distance and repeated in the shadow of the large grainstack, where it is juxtaposed first with a lightened cobalt blue and then with emerald

green. Monet's use of cobalt blue is evident in all of the long shadows thrown across the foreground of the scene with spots of it used at (almost) full saturation close to the base of the grainstacks (especially on the left side of the small grain-stack) and at the front edge of the canvas, just to the right off center. The gable wall of the barn is white mixed with cobalt. Otherwise the cobalt blue occurs on the far hillside in the center of the painting, mixed with white and in ambiguous forms in the middle distance around the smaller grainstack. Finally the sky portion of the painting seems to have been underpainted in cobalt blue and covered with lead white and yellow.

The rose madder occurs (as noted) in the grainstacks and in the roof of the barn. Rose madder reoccurs, mixed with white, in the highlights in the foreground and in several patches below the far ridge. A careful inspection of the highlights on the ground indicates that the highlights are at least as pink (rose madder mixed with white) as they are pale yellow.

The yellows in the painting present the most difficult problem of identification. It is known from Monet's color merchant that he used both cadmium pale "jaune de cadmium clair" and lemon yellow "jaune de cadmium citron" (House p.239) and it is very difficult to tell the two apart when they are mixed with white. Cadmium yellow and lemon yellow are both characteristic yellows and it is very difficult to describe the difference between them. Maybe the best way to capture the difference is to say that lemon yellow is a "warmer" yellow and cadmium yellow

pale is a "cooler" yellow. The reason it is difficult to tell them apart is that even the warmer yellow (lemon) when mixed with white, especially lead white, tends to go cooler.

The distinction between warm and cool colors is often misunderstood. By definition warm colors are reds and yellows and cool colors are greens and blues but this is a gross characterization and the nuance of color is much more ambiguous. Turquoise is a unique color, thought to lie somewhere between green and blue on a color wheel. That would make it by conventional definition a cool color but it is not. It is a markedly warm compared to indigo and even holds its own, in terms of warmth, relative to cadmium orange. Rose madder is an extremely warm red but deep cadmium red and mauve are relatively cooler. Cobalt blue is cool compared to rose madder but warm compared to prussian blue. Hooker's green light is generally warm while viridian blue tends towards the cool. Color considered on a scale of warm to cool tends to muck up all other scales (hue, brightness and saturation) because it does not correlate to any other phenomena of color sensation but it is a real facet of the perception of color and there is, statistically better than random agreement among observers, when asked to identify colors on this scale.

Ultimately the question of whether Monet used a warm or a cool yellow leads to an interpretation of the painting in terms of its overall temperature and in this connection the determination of exactly what yellow he used is not the deciding factor. The warm note of the painting is given in the rose madder and almost every other pigment in the painting takes on a cool tone

relative to this pigment. The exceptions are the emerald in the foreground shadow and the deep cadmium yellow in the highlights of the stacks. By modulating his colors in this way; opposing the warm rose madder, emerald, orange and some of the yellows to the cool cobalt, violet cobalt, viridian, burnt sienna and other yellows, Monet manages to set up what might be called a "base line" in the painting that takes the place of the base line usually played by the contrast of light and dark. Grainstacks is a painting which gives the impression of being very warm while, in fact, the colors which compose it are relatively cold.

The idea of a base line assumes that there are several levels on which the painting may be coloristically interpreted. In another sense the base line is a metaphor borrowed from popular music where the base line is the simplest carrier of the information contained in the melody. I am skeptical about analogies between music and color, partly because these are commonplace in abstract painting which, in the words of Roger Fry, tries to make of painting a "visual music" (1920:239); but, mostly because the foundation of music is based on the apprehension of sequential periodicities and the apprehension of painting is based on simultaneous contrasts. The perception of contrasts in painting occur in time, to be sure, but they are not of it. Be that as it may if it is in fact inappropriate to interpret Grainstacks on a fundamental coloristic level as the contrast between light and dark then some other relatively gross contrast must take the place of a reading of the painting on this fundamental level. This is the role played by the contrast

between warm and cool colors and it is like the base line in a good rock-and-roll song, it establishes a pattern for harmonic and rhythmic elaborations.

The warm-cool base line in Grainstacks is somewhat ambiguous in the details. Individual colors may, in isolation be either warm or cool and the question of what yellow Monet used still nags; but, the overall impression of the painting is, counter to the viewer's expectation, overwhelmingly cool. This is, I think, why Monet rendered the diffuse irradiation of sunlight in yellow. Had he rendered it in a red (warmer) tonality, which might have corresponded more accurately to the precise environmental conditions, he would have been forced to abandon the dominant cool tonality of the painting and abandon his stated goal: to render an enveloppe, "the same light diffused over everything". By rendering the primary source of light in a yellow that could be pushed cooler Monet suggests what cannot be explicitly rendered, the light context of the scene.

Monet wrote a letter to his dealer Geffroy on 7 October, 1890 that is quoted or alluded to in almost every book I have read on Monet. The letter is remarkable, for my purposes, in that he wrote it while he was working on the Grainstacks series, quite probably while he was painting Grainstacks (End of Summer). I quote House's translation.

> I am working hard, struggling with a series of different effects (of stacks), but...the sun sets so fast that I can not follow it ...I am beginning to work so slowly that it makes me despair, but the further I go, the better I see that it takes a great deal of work to succeed in rendering

> what I want to render: "instantaneity," above all the enveloppe, the same light diffused over everything, and I am more than ever disgusted at things that come easily, at the first attempt. (Claude Monet in House p.198, Wildenstein, letter 1076)

Monet was never a theoretical colorist. He always maintained that he minutely observed the landscape and took his clues, especially color clues, from nature. As John Gage (1993) notes Monet was remarkably unreflective about "the problematic nature of his own subjectivity, the effect of prolonged scrutiny of the motif on his eyes and his perceptions" (p.209). As a consequence, although Monet's concept of the enveloppe is always noted, it is not really taken seriously as a empirical observation of the conditions that obtain at twilight. The enveloppe is the perceptual result where "color is no longer seen as residing in surfaces but as suffused throughout the air in front of the spectator" (Kemp p.311). The impression of the enveloppe is supposed to reside in what one contemporary critic called Monet's "indigomania," and what most current critics ascribe to the predominance of violet hues in Monet's paintings.

I interpret the situation differently. I think Monet objectively perceived the preponderance of blue light at the gloaming, the secondary source of illumination from the dome of the sky, and recorded the corresponding shift in most of the colors in the scene towards their cool manifestation. He made some adjustments in local colors according to the dictates of rendering a scene in paint and he accentuated the violets and blues, to be sure; but, I take Monet literally at his word when

he says:

> I have at last discovered the true color of the atmosphere.
> It is violet. Fresh air is violet. I have found it!...In
> three years from now, the whole world will be violet.
> (Monet in Kemp p.311)

The enveloppe is therefore not a subjective phenomenon, some ambiguous word Monet picked in order to try to explain the magical effects he was creating. The enveloppe is a description of the way object colors interact with colored illumination so that perceptions beyond the spectrum locus can be re-constructed by our sensorium and yet remain constrained by objective conditions.

Monet, therefore, is a "realist" painter. He struggled through most of his productive life with the problem of painting representations of scenes that correspond in some way to the landscape depicted. The nature of his correspondences are such that they hover variously between simple recognizable shapes (e.g. the stacks) and decorative evocations (of aerial conditions). But, the most important correspondence in Monet's work is not the between the landscape and the representation. It is in Monet's reverse engineering, so to speak, of the process of perception in the landscape and his implication of that process in the viewer's perception of the painting. Grainstacks triggers recognition and although much of what we recognize is explicit in the forms and colors in the painting some of what we recognize is merely suggested by the painting and in only reconstructed in his appreciation. In short, Monet accurately observed the light context of Grainstacks and chose his colors in such a way that the enveloppe of the landscape can be re-created in a

viewing of the painting. In accomplishing this he tacitly acknowledges that the all seeing is a re-creation based on perceptual processes that are governed by subtly flexible neurological competencies.

The layering of color

The layering of color is a discussion of the ways human neurological competencies interact in visual processing. It is the most speculative part of the thesis and it is a speculation on how macro and micro visual responses interact in visual processing. The gross variables of the interaction are given by (1) the properties or conditions of the object, (2) the properties of the embedding media, (3) the process(es) of receptor(s), and (4) the conditions of the observer. The definitions of these variables are drawn from psychophysics where sensation is defined as the integration of the reflectance characteristics of objects, the spectral characteristics of the illumination (which is the medium of visual sensation) and the process(es) of the receptor(s) (which in the case of color sensation are the spectral sensitivities of the trichromatic receptors). Perception is sensation with additional unquantifiable (subjective) variables of visual processing supplied by the observer.

The role of the object in sensation is, of course, controversial, therefore; one may hold that either the properties of the object are sensed, given a realist conceit, or that the conditions of the object are sensed, given a hard nosed scientific reductionism. I think space and color are objective qualities of

the world, and that our perceptual mechanisms are tuned to convey information about these important characteristics of objects. If you do not agree simply substitute "conditions" for "properties" as I discuss "objects" below.

The properties of the embedding medium is a more general way to describe the variable that, in visual sensation, is the quality of the illumination. I assume that all sensory objects exist in a medium and that the medium in which they are embedded interact with the properties of the object that are sensed.

The process(es) of the receptor(s) are the variables that, as modes of perception, distinguish visual form auditory from haptic from olfactory perceptions. Each of the modes of perception are connected to attributes of sensation specifically tuned to the mode of perception. The attributes of visual sensation are numerous and in the schema of the Optical society of America include brightness, hue, saturations, size, shape, location, flicker, sparkle, transparency, glossiness and luster. The attributes of sensation are the psychophysical correlates of the properties of objects (fig.40). I assume, with the OSA, that these attributes of sensation are aggregated in perception.

The condition of the observer, severely proscribed in psychophysics by the conditions of experiment, in this thesis is given by the degree of abstraction of the viewer from the scene. Abstraction is defined in terms of displacement (or dissonance) and involves, simultaneously, attraction and distraction. The observer is attracted to the object observed and distracted from the observing "I". When this contradiction is resolved as the

transformation of an observer's existing conceptual structure (a realization), perception is said to be vivid. When the contradiction is resolved as (simple) recognition, perception is habitual. Perception grades from vivid to habitual and although the scale on which it grades is not infinitely fine, in practice there is no perfectly vivid nor solely habitual experience.

I should note in passing that there are many other conditions of the observer that might be explored such as prejudice or attention and that the degree of abstraction does not come close to completely describing the condition of the observer; but I assume the degree of abstraction is one very significant condition of the observer that conditions both what is seeable and how it is seen.

In an immersive[17] perception, object, media and receptors are integrated to create a full spectrum (all-sensory) impression of the environment. In this situation sound objects, visual objects, touch objects and smell objects are embedded in their respective media and sensed by their respective channels of reception; acoustic, visual, haptic and olfactory. All of the multi-channel information is available to the perceiving subject and the impression of the environment is built up from a dense sensory array.

In a "dominant mode" perception all the elements of an immersive experience are still available but the observer tends to concentrate on one mode of perception. When I regard the painting Grainstacks in the impressionist galleries at the Chicago

Art Institute I am not able to "turn off" olfactory sensations so that they play no role while I am perceiving the painting. I simply direct my attention towards the object which is best perceived primarily visually. Yet, on some level the olfactory, acoustic and haptic are still registered and may, at any moment, assume dominance. Therefore we attend to the environment in several senses at the same time and through this monitoring, though it may be dominated by one sensory channel appropriate to the object at hand, other information is constantly being mixed up with the information contained in whatever is the dominant mode of sensation.

Furthermore, there is a corollary to the relationship between monitoring the environment in subordinate modes and dominant modes of perception, when the dominant mode of perception is visually directed. I call this a scaling operation because we may sample the object of our perception as the environment, the landscape, the scene or any of several details (or subsets) of the scene. The model I am proposing does not define, for instance, that a ten degree angular subtense equals a "scene." I am simply establishing a principle of visual monitoring where: (1) the environment as object, the landscape as object, the scene as object, and three details of the scene as objects, conditions what is sensed in the visual array, and (2) where the all of this information is aggregated in perception and is potentially available in conscious visual processing.

I assume the environment is a global (360 degree) aggregate of multiple visual samples; the landscape is an aggregate of

multiple visual samples (that conditions more precisely the states of adaptation and accommodation); the scene includes foveal and extra foveal visual samples in single or multiple fixations (as in the interaction of successive and simultaneous contrasts); that three details of the scene as object exist in single fixations of different angular subtense and that all of these operations condition what is perceived and consciously known from the visual array.

Therefore, not only is there a dominant mode of perception in the environment at any given moment that is constructed to include information from other modes, there is also a dominant attribute of sensation that is constructed with information from other attributes of sensation that may, at any moment, become dominant--reversing the relationship between what constitutes foreground information and what constitutes background information in the visual array. I assume that this ability of vision, to establish as the perceptual object any of a number of objects, at any of several scales, is critical to the the interaction of micro and macro visual processing. I also assume that scaling has analogues in the other sense modalities (that I am not directly concerned with).

So far the model that I am proposing does not, at least, contradict conventional psychophysics. I assume that visual perception integrates an object, a medium and a receptor under conditions of observation called abstraction. I am shifting the emphasis from sensation to perception by factoring in vividness, since the observer is no longer identified solely according to

the properties of her receptor(s). Vividness factored into sensation pushes vision into perception in layers.

Layer One: Frame

I intend to develop the layers (or modules in David Marr's terminology) in reference to the above interpretation of Grainstacks. Layer one is developed by analogy to the photographic interpretation.[18] Where Monet is free to "fudge" the precise angle of the shadow that falls off of the large grainstack or translate the color of the highlights so that he pictures a specific balance between warm and cool colors, photographers, working outside the studio, are not free to do this. The skill of the photographer, insofar as it is not strictly technical, is in her choice of a frame for the scene. A photographer's first choice of the frame is whether to shoot in black and white or in color.

According to this analogy between the framing of photographs and the framing function of visual processing I assert that the simplest visual act we perform is in directing our view in a particular direction and that after that we frame the scene according to the relevance of different types of processing. The frame of a scene is not the same thing as the angular subtense of an image on the retina. I intend a meaning a little more metaphorical as in the correspondence of the order of processing and the salient information in the scene. In other words the frame does not operate at the level of the mode of perception

but at the level of dominate aggregates of sensory attributes. Since I am concerned with aggregates of sensory attributes called color, space and language I will assume that a framing mechanism picks among these aggregates, as a first approximation, to determine the order of processing for relevant attributes. In short, the frame is always frames (in time and space) and for this reason frame, as I use it, is different from frame vision (rahmenschau). It is different because the intention of the observer and information contained in the scene conspire to condition the order of visual processing.

Layer Two: Medium

Layer two is developed by analogy to the physical nature of light and pertains to the medium in which both space and color are embedded. Simply stated I think the medium of spatial objects and colored objects is light. According to this way of describing perception, color and space are both constructed from the sensation of light in a roughly equivalent fashion. Color is not a property of objects which, in turn, exist in space, implying the perception of color is a secondary operation, completed after a visual object is situated in space. Nor is color the product of an unrelated visual process. Color is sensed by means of some of the same visual processes which ultimately contribute to a different construction of space. Even though the processing of spatial information from the achromatic visual array seems to be a kind of default option, color processing at certain liminal junctures is on a different track from and parallel

to spatial processing.[19]

Level two, then, is concerned with an analysis of the medium (or the media) in which the object is embedded at its most primitive level. At this level colored objects, spatial objects and linguistic objects (sensed visually) are embedded in light. Light is sensed as either reflected or transmitted; but, reflection and transmission, on the microscopic level, blur into one another as different wavelengths of spectral energy often penetrate beyond the "surface" of an object. The reflection and transmission of light in the context of lots of microscopic objects blurs the distinction further since portions of spectral energy may be variously reflected, refracted or diffused with staggering complexity. Therefore, in considering the light medium in which objects are embedded it is best to remember that, even though the mathematical expressions of phenomena such as reflection, refraction and diffusion imply unambiguous surfaces where the the direction of light is modified, real objects have no such unambiguous properties.

Asserting that objects are embedded in light and that the absolute boundary between the medium and the object is complex beyond the ability of physicists to model (except schematically) appears to boarder on a most unscientific mysticism. Yet I intend this "mystical" union of object and light as a practical observation. It is actually easier, in my experience, to assume: that light rays are not equal to lines, that surfaces are not infinitely thin, and that colored objects and objects in spaces are fundamentally related in the light medium through which we

come to sense, perceive and (possibly) know them.

Layer Three: Shadow

Layer three is developed by analogy to the physiology of brightness. Brightness is the apprehension of a scene solely in terms of amount of brightness (or the log of luminance). We distill a tremendous amount of information from the brightness of a scene including, from the change in brightness, shadows and, from the change in the change in brightness, edges. Furthermore brightness information is dominant in the perception of depth by stereopsis (binocular vision effective only within a range of about fifteen feet) and in the perception of orientation (deviation from virtual reference "lines"). All of these operations may take place without any "color" information whatsoever and for this reason I think it is plausible to hypothesize a layer of primitive visual processing that ignores color altogether. The processing of brightness information to form shadows and edges is this layer.

The schematic formula for visual perception at this level integrates the object, the illumination and the sensitivities of the receptors, from the visual array through the two dimensional "primal sketch." Recall from above that the two dimensional primal sketch is composed of blobs, terminations, edges, virtual lines, etcetera that are aggregated through visual processing into the 2-1/2 dimensional viewer centered space, which gives surface orientations, distance from viewer to object, and discontinuities in surface and depth. The attributes of the 2-1/2

dimensional viewer centered space are, in turn, aggregated into a three dimensional object centered space, which gives volume and surface primitives (shape), the configuration of axes, and a hierarchical ordering of shapes. Layer three is intended to function up through the two dimensional primal sketch which is visual information that, although it contains no color, may contribute to later dominantly color processing. Color is not relevant for the additional processing that extracts information about the 2 1/2 and three dimensional attributes of the scene. These processes are spatially motivated and color only confirms what is known more certainly from achromatic processes. In conclusion, layer three, called shadow, is the level where illumination in its most primitive manifestation as light or dark, is processed.

Layer Four: Color+Brightness

Layer four is developed by analogy to the trichromatic processing of light. Where the brightness module (layer 3) processes only achromatic information, layer four processes the relationship between lightness (as brightness) and color (as dominant wavelength), called chromaticity. That the spectrum locus becomes the limiting case of this relationship is not surprising since homogeneous color is, by definition, at the limit of the interaction of color and brightness.

The schematic equation of this level integrates the function of the brightness module with the object, illumination and trichromatic receptors, from the visual array through the two

and one half dimensional space. A two and one half dimensional space is the "space" of a topographical map which gives two planar dimensions and half of the third dimension of depth (it does not give concave "undercuts"). This two and one half dimensional information, though achromatic and derived from brightness processing, can be mixed with chromaticity information to give the transparency, glossiness, and/or luster of surfaces. At this level neither spatial nor coloristic modes dominate, the two existing in relative equilibrium.

At layer four visual processing is assumed to be taking place at a retinal level, as in the brightness response; but in this case the retinal sensors are evaluated simultaneously by a light-dark stimulus and by a dominant wavelength stimulus, expressed in terms of trichromatic outputs. The response can be correlated with two and one half dimensional information from a spatial processing track, to give additional characteristics of objects in the visual field.

Layer Five: Adaptation

Layer five, the color of color, is a very significant extension of layer four, the color of brightness. Layer five, developed from the implications of opponent processing, grew out of questions left unanswered in trichromatic processing. This module, that reads color in the context of color (and the resulting impression of super-saturation) though perception, is no less real than the impression of color itself.

Even though referring to layer five as the color of color

sounds like a poetic evocation, I submit to you that it is a coldly accurate description of adaptation. Adaptation is measured on a graph of chromatic valence and wavelength. Chromatic valence measures the response of the receptor to target colors under colored illumination, in other words the color of color. At this level brightness information is, at best, background information and color processing is fully engaged. The schematic formula for this layer of processing integrates the object, achromatic illumination and trichromatic information, from the visual array through the 2-1/2 dimensional space (layer four) with information about the object under chromatic illumination at a processing site that is no longer in the retina, from visual the array through the 2-1/2 dimensional space.

Opponent processing at layer five, though linked to trichromatic processing in the retina, is presumed to be a later, non-retinal, analysis of visual information. This later processing seems to be a means whereby the visual system heightens a color signal analogous to the way lateral inhibition intensifies a minute difference between the signal sent from neighboring retinal receptors. Opponent processing could not occur at the level of the retina since trichromatic processing does not allow for colors saturated beyond the boundary of the spectrum locus.

Layer Six: Displacement

Layer six is developed by analogy to perceptual psychology. This is the layer where linguistic phenomena begin to be integrated in the process of perceiving distributions of light as

color. What is called a "memory color" is a good example. The canonical example of memory color is of a banana. Since ripe bananas are yellow, (North American) experimental subjects tend to identify the hue of a specific, not yet quite ripe banana, as yellower when it is in fact, slightly greener. In other words it seems that our reading of recognizable shapes effects the perception of color by a kind of forward matching where warranted expectation affects what is actually perceived. It is a variation of the way the tendency to classify disturbs the activity of seeing in apperception (discussed in chapter four). In the end our linguistically motivated expectations not only get in the way of accurate sensing but actually supply erroneous "data".

Level six, is the process of integration where simple linguistic information is connected to other, dominantly visual information. It is critical for displacement. At this layer non-retinal processing is complicated by the association of memories, categories and names with incoming visual information. This is, of course, a brain function, but; it is not necessarily a "higher" brain function since many of these associations, I assume, are attached to the information from the visual array before we are even aware that there is an image to which we might devote our attention.

Layer Seven: Correspondence

Finally, layer seven is developed by analogy to painting. This is the module that reconsiders sensations and perceptions that are ambiguous, by a kind of reverse processing. This module

is a relatively sophisticated mechanism that allows us to "reverse engineer" the process by which we arrived at a sensation that is questionable, attempt to discover the source of a mistake and correct it. Painters develop this facility as part of the experience of painting and often discover in perceptual "mistakes" the impetus of their technique. Michael Baxandall expresses the idea well.

> The painter must backtrack down the channels of perception, undoing the integration of features that is higher perception's achievement, pushing right back down to the early visual modules of brightness, colour and the rest--which have a degree of homology both with his professional concepts and his physical methods. (Baxandall 1994;130)

The schematic expression of this layer is potentially quite complex because it nests a series of object and illumination pairs. The basic interaction of the visual object and its illumination is modified to account for a regress of reproduction(s). In this model of visual processing perception integrates the source object and the source illumination into an aggregate virtual object that is, in turn, integrated in another illumination context with the receptor of the observer, etcetera.

What I am describing is what happens in a viewing a reproduction. The source object exists in an illumination context which is recorded either through the filter of a person (as in a painting) or through the filter of a mechanical prosthesis (as in a camera). The resulting reproduction then exists as an object in its own right which, in viewing, has its own illumination context and the source object becomes a virtual object.

Models of visual processing must be able to explicitly allow for several generations of this kind of regression since, as is the case in my analysis of the Monet painting, I am working from a reproduction of a reproduction of a source scene. This also means that there are three illumination contexts all of which should be explicitly modeled. In practice this is not difficult to do since since the reproductions may simply be embedded in their illumination contexts by writing a schematic formula thus: perception= {[<source object x illumination x receptor> x illumination x receptor (of reproduction one)] x illumination x receptor (of reproduction two)} and so on.[20] The point is two fold: (1) that human visual processing can backtrack through this regress with amazing facility (reverse processing) and (2) that the different processing strategies, coloristic, spatial and linguistic, create the regress in different ways. I will not detail the different ways different processing strategies create the regress and, though artists develop this facility to a very high level of competence, I assume most observers have a native ability to unravel aggregated perceptions into individual sensations and to recombine the sensations into different configurations in order to arrive at different correspondences between sensation and perception.

Summary of the Layers of Perceptual Processing

I have developed the layers of processing for two reasons. Primarily I intend to use the layers of as a schema in which to discuss "Sunflower at Sunset Yellow" and vividness in Balthasar

Neumann's Church of the Holy Cross. The layers provide a logical basis on which to link the interpretations of Grainstacks to the affects of vividness in a Kansas landscape linked in turn to the vivid experience of a building. Therefore, in this context I will use the concepts frame, medium, shadow, color+brightness, adaptation, displacement, and correspondence, as the common points for an analysis of the Kansas landscape and the Baroque church.

Secondarily I am concerned with an additional point that needs to made about the interpretation of visual phenomena and its relationship to hierarchical layering of visual modules. I intend the word "interpretation" to refer to both the process of decoding clues given in the visual array and the process of ascribing significance to visual information. The precise nature(s) of the layers, and I have described them only approximately, are not what I am specifically concerned with. David Marr offers a more detailed and much better scientifically grounded exposition of the modules of visual processing. His model constructs visual processing from the bottom up and asserts visual processing is, "in principle," consistent at the micro and macro levels. I agree that the macro and micro levels of visual processing are connected and dependent upon each other. My purpose here is to speculate on the nature of the connections using the analysis of the perception of Grainstacks as a test case.

I am less convinced than Marr that visual processing always takes place from the bottom up in a static hierarchy. It may al-

ways take place from the bottom up; but, I think what constitutes the "bottom" is flexible (but not infinitely variable) and that the order of the layers is organized by the frame in which we see things. In short, there are a variety of ways the modules may be combined and the constraints on what combinations are possible are given by different desirable ends.

Since the model I am proposing is as concerned with the perception of a painting as with micro and macro descriptions of visual processing, the model exists in a tradition of theories of visual processing common in aesthetics. If the macro and micro descriptions can to be shown to be consistent, they must be able to describe phenomena as perceptually complex as works of art and architecture. As John Gage remarks:

> perhaps the least developed area in the history of color is indeed the area of spectator response [what I have called the problem of color appearance], and this is probably because the very impressive advance in the modern understanding of color vision have not been imitated by advances in the theory of color perception. It may well turn out to be in this area that the historian of art has most to offer the sciences at large. (Gage, 1990:535)

Roger Fry, an art historian, offers a schema for a macro description of visual perception in his essay "Vision and Design" (1919). For Fry the layers are: biological vision, curiosity vision, aesthetic vision, and creative vision. Biological vision is the 'meaning-for-life of appearances', an assessment of the utility value of visually perceived objects. Curiosity vision is the view of objects that 'stimulates our social-historical imagination'. It is a pleasing vision of the 'peculi-

arities of color or shape' and is related to ornamentation. Aesthetic vision is a 'harmony of form and color' beyond the curiosity of ornament, available only in a work of art. Aesthetic vision "is at once more intense and more detached from the passions of the instinctive life than either of the kinds of vision hitherto discussed" (p.49). Creative vision, Fry's fourth type of visual perception,

> demands the most complete detachment from any of the meanings and implications of appearances...objects as such tend to disappear, to lose their separate unities, and to take their places as so many bits in the whole mosaic of vision. The texture of the whole field of vision becomes so close that the coherence of the separate patches of tone and colour within each object is no stronger than the coherence with every other tone and colour throughout the field. (1956:51-2)

In the end, for Fry, the different types of vision are related as in the gears of a car and though we may go from second to third gear without knowing it, the levels are hierarchically related as the ratio of teeth in a drive shaft.

It is the assumption of rigidly hierarchic arrangement of visual processing in both theories of art and theories of science that disturbs me most. It assumes a fixed progression through levels of processing that, in all visual experiences, must be traversed in the same order. Although I think that there are "higher" and "lower" levels of processing that are linked to the complexity of the visual task, I believe the order of processing is variable depending on the frame of reference. In other words the order of processing is suggested as much by the

type of information contained in the scene as it is by the way attention is consciously directed.

I hypothesize three frames of reference, based on the discussion to date. I call them the linguistic frame, the spatial frame and the color frame. An initial determination decides whether the interpretation of a scene is going to be constructed linguistically or visually. If the viewer decides the scene is to be linguistically processed apperception is not suspended, the basic categorical function of language is engaged and primitive visual information is interpreted in terms of its relationship to linguistic categories. In this scenario an observer is actually looking at language through color, through the information contained in the visual array. The aggregated processing response concentrates on reading the scene in terms of the "labels" we attach to recognized shapes or colors. In this instance a schematic bit of color is aggregated with primitive brightness information and associated with things already known and/or experienced and translated into appropriate action.

I associate this processing scenario with stopping at a red light (biological vision based on a utilitarian value); but it might equally well be associated with the appreciation of an ornament (curiosity vision), the recognition that a painting one has never before seen was painted by a particular painter (aesthetic vision), or the incorporation of a familiar graphic gesture in a new drawing (a manifestation of creative vision). According to the scenario I am proposing: a hierarchy of processing is followed on a micro level (since the micro level pro-

cessing of the "brightness" layer nets basic information that is required for all subsequent processing) and on the macro level a branching occurs where the association function of linguistic processing is engaged in such a the way that the interpretation of spatial and coloristic information generated in visual processing is ignored.

Given a visual processing response the framing function kicks in and one is faced with the choice whether a scene is going to be read in terms of shape or in terms of color. If the scene is read in terms of shape the local lighting response dominates the global lighting response which is, in turn dominated by the micro sensing response. Again the micro sensing response leads the order of processing because most of the information in the scene is contained in the shadows, which give depth and are read from the local lighting conditions and in edges which give shape as well as figure / ground relationships. The combination of depth from shadows and depth from occulusion (which are spatial relations in an object centered coordinate space derived from figure / ground relationships) finally leads to the situation of the body of the observer and the object observed in the same space.

In this scenario color is not required for any of the information derived from the scene. It is of secondary importance (as it is in linguistic processing). The observer is reading formal and spatial clues, which may function as biological, curiosity, aesthetic and/or creative visions. Furthermore the observer exercises a measure of freedom in the choice of subse-

quent processing. One observer may connect the name of shapes recognized and head off on a trail of categorical associations (linguistic processing). Another observer may become interested in colors in the scene. In this situation a color reading of the scene is somewhat limited because it is built upon the interpretation of color in terms of brightness, yet; this approach is a perfectly good interpretation of color--it is only limited in relation to color processing of colored objects.

A different approach to interpreting color is also available. In this third scenario a global lighting response is engaged to which the local lighting response is subordinated. This situation concentrates on an opponent processing response (the color of color) which dominants the aggregated sensing and (probably) the micro sensing responses (or in some way recalibrates the micro sensing response so that it is more concerned with surfaces and less concerned with coordinate spaces). Assuming apperception is suspended in this case the scene is read in terms of the mosaic of colors and the perception of color dominates the scene.

I am not wed to any of these scenarios because I regard them as a first approximation of some of the types of processing that transpire on a regular basis. The conclusion I would like to draw, before a more detailed consideration of dominantly colored visual processing and of the role of color in a dominantly spatial visual processing is simple. Visual processing is stratified but not rigidly hierarchical. It is hierarchical in the sense that visual information is progressively constructed

with each layer processing further the information contained in the preceding layer; but it is not rigid because the layers selected to perform further processing, at certain liminal junctures, may be consciously selected, which radically affects the information derived from the scene.

Furthermore, I believe there is information contained in the order of processing (which is combined periodically with the information processed) to condition the choice of the type of subsequent processing. In this way the flux of the world is built up in a continuous process of sampling, sifting for clues and resolving ambiguities into recognitions. Displacement is our brain's way of tripping the reset button so that what we take for granted in the constant scanning of the visual environment can be seriously (re)considered. Vividness is the reward we experience for the hard work we perform in reconstructing an unfamiliar scene from scratch.

Notes to Section Five

1. There are four early canvases from 1889 that may or may not be considered part of the series proper. Three canvases are dated 1890, twenty-two 1891 and one is not dated. About the series Monet said they "only acquire their value by the comparison and succession of the entire series" (in House, 1986:201). I appreciate Monet's claim because I had the good fortune to see nine of the canvases in the Rouen Cathedral series together. The individual paintings marvelously complement each other. Unfortunately this analysis concentrates on only one of the Grainstack series.

2. Wasily Kandinsky's (1866-1944) account of viewing Grainstack in Sunlight (1891,fig.55) in Moscow in 1895 is as follows:

> Previously I knew only realistic art...Suddenly, for the first time, I saw a "picture." That it was a haystack, the catalogue informed me. I could not recognize it. This lack of recognition was distressing to me I also felt that the painter had no right to paint so indistinctly. I had a muffled sense that the object was lacking in this picture, and was overcome with astonishment and perplexity that it not only seized, but engraved itself indelibly on the memory and, quite unexpectedly, again and again, hovered before the eyes down to the smallest detail. All of this was unclear to me, and I could not draw the simple consequences from this experience. But what was absolutely clear to me was the unsuspected power, previously hidden from me, of the palette, which surpassed all my dreams. Painting took on a fabulous strength and splendor. And at the same time, unconsciously, the object was discredited as an indispensable element of the picture... (Kandinsky (1913) in Seitz 1960:32)

3. It is amazing to me that Tucker could write a whole book on Monet's series paintings and not engage the work as a tour de force of the painter's rendition of light and color, but he remarks only in passing on these aspects of the paintings, presumably because that subject has been treated elsewhere. I am guilty of the inverse omission.

4. This sub-section is based mostly on personal experience taking pictures and working with photographers. There are no specific textual references for the information contained within; but see Minor White's The Zone System Manual (1961) and Ralph Evans' Eye, Film and Camera in Color Photography (1959).

5. It should not be surprising that the conventions artists and architects use to render volume in drawings (a source of light that throws a shadow, according to the rules from a 45 degree angle) photographers also use in photographs (a direction of light oblique relative to the horizon). This convention helps shaded patches on a flat piece of paper seem as if they have dimension.

6. The exposition of this sub-section depends primarily on Michael Sobel's *Light* (1987) and Aden and Marjorie Meinel's *Sunsets, Twilights, and Evening Skies* (1983).

7. Sunlight is a distribution of spectral energies that is characteristically "white" light but tungsten and fluorescent lights are also perceived by human observers as "white".What is important to remember is (1) that "white" light is decomposable into spectral energies that appear in isolation to be colored but that when mixed together yield "white" (achromatic) light, and (2) that different combinations of spectral energies appear equally "white".

8. I am far from being expert concerning matters of physiology,

therefore, this chapter is drawn mostly from David Marr's Vision (1982) and partially from Tom Cornsweet's Visual Perception (1970).

9. The terms Marr uses are: zero-crossings, blobs, terminations and discontinuities, edge segments, virtual lines, groups, curvilinear organization and boundaries. Since I am only concerned with an exposition of one module of the primal sketch, I have rendered his technical terms in a more general vocabulary so as not to be drawn into a comprehensive discussion of his findings. The more general vocabulary may, however, be somewhat misleading therefore see Marr (1982:41ff) for a technical definition of these concepts.

10. This chapter draws on the primary source material of Deane B. Judd and David l. MacAdam (see bibliography), and on excellent expositions by Ralph Evans (1961), George A. Agoston (1987), and Rolf G. Kuehni (1983).

11. This chapter follows closely the argument presented in Jameson and Hurvich (1956). See also C.L. Hardin (1993) for an argument that utilizes the findings of opponent processing in the context of philosophy.

12. Adaptation to white light is called neutral (chromatic) adaptation.

13. For the exceptions see Kubovy (1988:65ff). Enumeration of the contraindications here would take up to much space and suffice it to observe that the exceptions are all in the tradition of trompe l'oeil painting which attempts to delude the viewer as opposed to enlisting her collusion.

14. I had the opportunity to watch the progress of the cleaning of a series of four murals on canvas by Thomas Hart Benton (in

the collection of the Nelson Museum of Art in Kansas City). Before cleaning the dominant tonality of the paintings was amber. After cleaning an inspection of these canvases showed Benton to be a superb colorist. The paintings could no longer be said to have a dominant tonality as the full range of ocher, cobalt, and rose emerged from what could only be previously described as damaged canvases. For a good article on the restoration of the Sistine Chapel ceiling see Jacob Beck (1988).

15. Even standing in front of the actual painting using contemporary color charts--since Monet's viridian was, in all probability, slightly different than Windsor and Newton's current viridian--is slightly different than Grumbacher's viridian, etcetera.

16. I want to thank Suzanne Najaman for assistance in recontructing Monet's palette.

17. I am indebted to Sandy Stone for this distinction between a broad bandwidth experience, which is dense, and a narrow bandwidth experience, which engages more of the participants' interpretative faculties (Stone 1995;92ff). An immersive experience engages more sense modalities and is therefore dense. She uses the word "immersive" in the context of virtual reality and since, for her agency is marvelously problematic, there is not a transparent connection between one body and one observer that can be abstracted. I don't disagree, I am simply attempting to model multiple viewpoints as the interaction of object, medium, receptor and degree of abstraction that occurs in the process of attaching signification to sensation.

18. One must be careful proposing analogies between photography, painting and perception because photography is essentially a mechanical process the technology of which is only superficially analogous to vision.

Cameras depend on lenses and the eye has a lens and that is about as far as the analogy between photography and seeing should go. The retina is an active processor of light, unlike film. The retina is variably sensitive over the area of light it samples. The image projected on the retina is not flat. The "simple" lens of the eye accommodates for depth of field differently than a compound camera lens; etcetera. The eye is not a camera obscura and all too often this easy analogy has lead to misleading conclusions, particularly about the supposedly perspective representation of vision.

Taking photographs and painting paintings both produce pictures and this is about as far as the analogy between photography and painting should go. Photography is not more realistic painting and painting is not more creative photography. Both are active processes that require decisions on the part of their creators and, though they are fundamentally different processes, one of these differences suggests something important about the nature of primitive visual processing.

19. I grant that the decoding of spatial information has a biological priority since, to the best of my knowledge, no one was ever killed by a color whereas many people have died slipping off a cliff or by misjudging the distance to a dangerous animal; but we do not live only in a biological world and in principle, I think the decoding of spatial clues should not necessarily receive precedence in the decoding of elements from the visual array.

20. I am indebted to Bob Mugeraurer for reminding me that Carl Foss (Foss 1949;184ff) deals schematically with complex mathematical formulas in just this way.

THE COLOR OF SUNSET; SUNFLOWER AT SUNSET YELLOW

The very word apparent still languishes in the shadow of Plato's disdain. We tend to assume that appearance lies some distance from the truth. But the grid of the [Barcelona] pavilion suggests that there might be circumstances in which appearance is the final arbiter. If what we seek is appearance, then appearance must be the measure of truth, at least temporarily. That is what happens when things are made to be looked at. Appearance is never the whole truth, but it is true to itself, and it is made more evidently so by the visual arts, especially when they play tricks with sight. Plato was wrong. These tricks do not deceive us; they sharpen our perceptions. Robin Evans (1990:60)

Chapter five uses Grainstacks (End of Summer) as an artifact in which the traces of Monet's vivid perceptions of the Giverny landscape are presented in the viewer's field as the kind of vivid experience called art, but the actual colors in Grainstacks are not problematic. No color is physically saturated beyond what visual science can account because the impression of vividness is a product of the viewer's engagement with the painting as a work of imagination. Chapter five also argues that painterly representation, though it may also mimic an object, mimics processes of perception. In other words a representation is not vivid only because it evokes a string of causality that leads back to the vivid source object, but because it encourages the viewer to supply information missing in the representation, information derived from watching

yourself watching.

In Chapter six I turn to an analysis of "Sunflower at Sunset Yellow" to analyze an experience of vivid color that is not filtered through the eyes and technical competence of Monet and to show how the layering of color functions in a direct perception of the landscape. Of course, the readers' perception of the western Kansas landscape is not direct. It is mediated by a story and, as such, the whole situation is even more problematic. At least, in the interpretation of Grainstacks the reader may return to the object and check my story against their experience; even though no one may "check" Monet's interpretation of the Giverny landscape. Sunflower at sunset yellow (the color) is like Monet's painting in so far as no one can check the object of the perception to see if my description matches, even approximately, their experience.

Referring to the perception of sunflower at sunset yellow as direct is doubly problematic because "direct" also implies "unmediated" and no perception is, by von Helmholtz' definition, unmediated. Perception is sensation mediated by the channels doing the sensing and the "I" decoding, perceiving and interpreting the sense data. Since no one can demonstrate (one way or the other) whether sense data corresponds to an object of perception, everyone is left to decide for themselves whether or under what circumstance objects and sensations correspond. I have adopted a realist point of view and phenomenological approach, since I believe, with Ernst Mach, that "abstract concepts draw their ultimate power form sensuous sources"

(1894:93). Furthermore, I am under no illusion that my interpretation of sunflower at sunset yellow is "true". It is a fiction and any truth claim the story makes, it makes as fiction. This implies that my interpretation of the acts of perception in the scene, no matter how informed by psychophysics, is a criticism of a science by fiction. This is precisely my intent. The goal is nothing more--though nothing less--than to provide a plausible, if idiosyncratic, description of sensation as vivid perception in a Kansas landscape.

The following interpretation of sunflower at sunset yellow (the color) assumes that the general conditions laid out in sections three, four, and five apply. In this chapter, as in chapter three, I assume the abstraction of sight in psychophysics offers a very robust model of the sensation of color, so long as it is tempered by attraction and distraction. Attraction, of which attention is a necessary but not a sufficient condition, is conceded to the object of perception. Attraction locates the viewer and the viewed in the same medium and, in more extreme cases, links object and subject in participation. Distraction momentarily diverts the superseding "I", contributing to a retrospective impression of vividness. The seeing "I" is soon re-established and the discontinuity among different types of evidence is one basis on which we ascribe meaning to perceptual events.

This schematic description of displacement (and of what happened to me in the west Kansas landscape) is accurate, as far as it goes. The perceiving "I" was shaken up, momentarily

displaced, and the significance which, in retrospect, I ascribe to the event, challenges the adequacy of psychophysical definitions of purity, chromaticity and saturation.

I assume, as in chapter four, that the tendency to categorize a sensation before it is properly visually perceived can be temporarily suspended. I call this the "suspension of apperception" and it is converse to the "suspension of disbelief" upon which playwrights depend. In the theater, if an actor says a stool is a mountain we provisionally grant that the stool is a mountain in order to allow the actor to weave her magic. In visual perception we provisionally suspend the recognition that the ground cover is green in order to allow the color of the ground to be what it is, possibly sage, straw, ochre, etcetera, so as to allow the material colors to weave their magic in perception.

Finally, as in chapter five, I assume that visual experience is layered. The layers (frame, displacement, medium, shadow, color+brightness, adaptation, and correspondence), combine in different configurations to yield perceptions from sensations. Chapter six follows this scheme in order to account for the vivid perception of yellow and finally to describe one way the psychophysical model might be extended to include super-saturated colors.

The Frame

The frame for my experience of vivid yellow was set by Steve Thompson, a chemistry professor at Colorado State Univer-

sity. Dr. Thompson and I met several times during the summer of 1992 to discuss color. He is a scholar whose current research involves exploring practical methods for teaching science. He is one of a group of professors exploring the pedagogy of science for beginning students under a National Science Foundation grant. I was late leaving Fort Collins for my long trek across Kansas because we had spent three hours brainstorming ways basic physical concepts might be introduced to students through the teaching of color. During the course of our conversation he asked, somewhat rhetorically: "What would happen if we considered color not as a code for some other property of objects, but as providing information fundamental to those objects?" He was speaking as a chemist, not so much considering color for what it reveals about the nature of light or of sensation but for what it reveals about the nature of the compounds studied. I take this to be a chemist's "material" prejudice since spectrography is such a basic tool in chemistry, a tool that gives fundamental information about the compounds analyzed.

At the time I was struggling to grasp the physical model of light and the question stuck in my mind. According to the physical model of color, objects are every color but the color they appear to us. This refers to the assumption underlying scientific models that the light objects reflect (and that we sense as objects' color) is the distribution of spectral energies that have not been absorbed by the material of which the objects is composed. Coloquially speaking, objects in physical science are every color but the color they appear

to us. In chemical science, on the other hand, the material composition of objects is given in their spectral signature. From the point of view of physical science it is folly to think color conveys some scientifically significant--yes "primary"--quality of objects. Yet, that is exactly what chemists and astronomers depend on. I left Fort Collins intrigued with this possibility, trying to imagine what a science of color as fundamental as Newton's and broad as Monet's would look like.

I formulated this musing as an explicit question and promptly forgot it. I had other things to occupy my attention, like the rain which promised a thorough soaking of my bed if I didn't get going, or if I followed 25 south to 70 east. I needed an alternate route that took me due east out of Fort Collins. There was only one choice. I took it.

Even though I promptly "forgot" the question "What does color express?" it was present as a frame. Many subsequent sensa from the next three hours on the road did not fit within that frame and if I told a different story about the same trip, for instance one about the geomorphology of the high plains, the question would no longer function as a frame. This is the funny thing about frames: a frame is a frame only in retrospect. Frames are expectations, means of limiting the myriad possibilities of what might happen at any given time or place; yet, any given frame is as much a part of the landscape framed as it is a product of the framer's intentionality. The trick is to limit possibilities in such a way that the unexpected may still occur. I think the best way to do this is to explicitly formulate

expectations as questions and then allow the questions to lie dormant until an appropriate scene engages them.

Displacement

Displacement occurred for me in western Kansas in two stages. One was shocking and the other was more gentle. Initially the shock of sun reflected off of the "No Passing Zone" sign interrupted my unidirectional musings. I cannot emphasize enough how disturbing this event was. I experienced it as an explosion with all of the attendant concern for life and limb. Even If I had not been lost in Kansas, lost in thought, I would have reacted strongly to the stimulus. It brought me 'back to my senses' in a manner consistent with any imminent threat of bodily harm. Passing time is attenuated so that sensory samples of the environment are processed in shorter intervals. Visual scanning becomes tunnel vision (rahmenschau), directed towards the source of potential danger. Adrenalin is released into the system in anticipation of flight or fight.
A musing attention gets reconstituted as acquisition, in the sense that a target is acquired.

I am not in danger, although a false alarm is an alarm nonetheless and the heightened visual inspection of the landscape does not pass as quickly as the no passing zone that prompted it. This is the moment where the scene engages the frame. The sunflowers appear as saturated as the sun. I stop and experiment with the effect.

At this point intention is directing attention. Even though

conceding much authority to the landscape, I am also seeking to discover some piece of evidence to justify the impression that sunflower at sunset yellow is more saturated and of a different hue than a fully saturated yellow characterized in psychophysics as unique yellow. No easy answers are evident. I am left to soak up and record in scribbled notes as many observations as I can. These observations became "Sunflower at Sunset Yellow."

The point I wish to make about displacement is that, for me, the physical shock of visual interrogation and the gentler shock of recognition are usually simultaneous. Though I may later rationalize any given recognition as vivid because the impression of distance between me (the interpreting subject) and "the thing" (an object of observation) seems to have been diminished. A careful consideration of displacement indicates otherwise. Displacement is a sorting of what is known into new categories and as such takes place at a very abstract level. It cannot be solely a function of the perceived immediacy of the stimulus. Yet the impression of perceptual immediacy is undeniable.

In the Kansas landscape the shock of all-sensory attention was temporally separated from the recognition that psychophysical categories could not adequately explain what I was seeing. I later realized that impression of immediacy and the abstraction of recognition are distinct and that the lingering scent of wholeness, the unity of subject and object in the act of perception, indicates something very odd about visual perceptual processes.

It is quite common for intellectual models to become

progressively more abstract. In the abstraction of sight, for instance, participation with the object of perception (Aristotle) is abstracted by the imposition of a frame between subject and object (Alberti), is abstracted again by the imposition of a mathematical filter between object and subject (Newton), is abstracted by the absolute disjunction of sensation and perception (von Helmholtz). Perceptual processes seem to function differently. Given perceived danger, we respond very directly and very immediately to perceptual information. It could be said that we participate with objects in our perceptual frame of reference in order to preserve our existence on the most fundamental level. Removed from imminent danger we participate less in the environment through our perceptions and, although the mechanism(s) of attention dampen or heighten our engagement with objects, what we see is filtered through a seemingly ever present ego. What is remarkable is that in an extreme case of intentionally directed attention, relatively abstract phenomena get reconstituted as participatory events, much as they are in threatening situations.

It is as if there is a scale that grades from immediate perceptual events to mediated perceptual events in terms of increasing abstraction, but that at some point--call it "abstraction squared"--the highly mediated phenomena appears unmediated. The moment does not last. Yet, brief as it may be, I seem to be able to vividly recall sunflower at sunset yellow in much the same way that a childhood memory of almost being hit by a bus is still vivid. In the final analysis, if sunflower

at sunset yellow is vivid only by virtue of attraction to the object and distraction from the ego, it may not be a physical phenomenon at all, merely a kind of mirage, the product of an over-active imagination. Certainly it is this and, I maintain, it is also the consequence of measurable physical phenomena.

The Medium

The medium in which sunflowers exist is light. I learned a lesson about looking through light at surface lights (reflected), looking at the the seed portion of the sunflower. The seed portion is

> brown, velvety, deep in hue and highly saturated. Looking again, closer; the seeds are softly brown, rust-brown, ochre-brown, and walnut-brown in a variegated dark chocolate with a yellow halo. It is a totally different color, related to "linguistic" brown but richer, thicker.

At this point I am standing within ten feet of the flower. In this minute inspection I cannot quite locate the surface of the seed portion. This is to be expected since ten feet is just about the right distance for the seeds of the flower to fuse optically. In other words, using the most telescopic foveal vision, I can just make out a suggestion of individual seeds, but it is stressful maintaining this degree of resolution. When I allow my acuity to relax a bit the seed portion goes slightly out of focus in the sense that I do not resolve the smallest scale of formal detail. It seems that I am looking at a convex surface, although the detail of the surface remains ambiguous.

Let me illustrate using the example of mirrors, smooth sur-

faces with a glossy coating and smooth surfaces with a matte coating. The spatial location of matte wall surfaces under most lighting conditions is, for instance, more ambiguous than the location of glossy wall surfaces under the same conditions. A matte surface, by virtue of microscopic irregularities, scatters more light out of the line of sight than does a glossy surface, which tends to maintain the directional integrity of the light incident to the surface. Glossy surfaces can give a very good clue to the color of the illumination because the highlight or specular reflection of the incident illumination, at the correct angle of incidence, tends to display not the color of the substrate but the color of the illumination. Matte surfaces do not behave in the same fashion. Matte surfaces both absorb and scatter more of the incident illumination and, if they show a highlight, it is much subtler. Therefore, matte surfaces are "softer." It is more difficult to pinpoint the location of the surface because there is no highlight, to facilitate determining distance to the surface.

Mirrors present a special case of specular reflection that the eye compensates for by changing the distance of focus. The technical term for this is accommodation and it is quite easy to change one's focus so that we are looking at the mirror (which is easier to locate in space than even a specular reflection) and so that we are looking at ourselves in the mirror. Obviously, the location of mirrored surfaces can, under certain conditions, be made quite deceptive. I am not maintaining that the surface orientation of mirrors are always clearly determinable.

I am only correlating specularity and the accurate judgment of distance. Matte surfaces are more ambiguous than glossy surfaces which are more ambiguous than mirrors. More ambiguous still are surfaces considered just at the point where small scale detail fades into a larger scale form. The best description for this phenomena is "thick." The surface, because its distance from the observer is ambiguous, appears deep, thicker than even a matte surface. It radiates color.

This effect, of variegated color viewed nearly from the distance of fusion, captures a complex interaction between a medium and a surface. Since the surface is ambiguous the tendency to shift from the 2 1/2 dimensional, viewer-centered, coordinate space to a 3 dimensional, shared viewer/object space, is aborted. We become briefly stuck in the visual decoding of spatial relations, with at least three ways to get un-stuck. We can (1) shift visual scale so that we construct space from larger shapes, (2) attend to the coloristic character of the scene at that scale, or (3) name something.

Assuming a coloristic analysis (number 2 above) I suppose we favor the reading of surfaces to the reading of homogeneous space. It is as if the eye trades the richness of space for the richness of color surfaces and recognizing the salient characteristics of the illuminating medium is a learned skill. One must learn to decode the fugitive clues of light, shape and color from surfaces. It is like drawing without outlines.

The relevance of 'softly brown, rust-brown, ochre-brown, and walnut-brown in a variegated dark chocolate' is the way the

medium, the object and the observer interact to create a thick object color. This tendency of objects, to irradiate (glow with thick color), is a function of the relationship between distance and detail frequency and it occurs most profoundly upon close inspection of relatively near colored objects. The impression of thick color results only under particular conditions, but it intensifies colors beyond what we might expect the most saturated colors to look like, given standard psycho-physical experimental conditions.

Shadow

Ralph Evans in his essay "The Perception of Color" (1972) presents a remarkable demonstration of the relationship between edge detection and color saturation. He illustrates four dots of color with different edge conditions. The smallest spot, 3/8 inch in diameter, has a hard edge. In the next spot the edge is smooth but not hard. In the next spot the edge is fuzzy and in the final spot the edge is indistinct (fig.80). As far as the technology of printing allows, only the edge conditions of the circles vary.

What is remarkable about this simple demonstration is that the perceived color of the entire dot changes depending on its edge condition. The cyan spots become progressively less blue as the edges become progressively more indistinct. What this example of the relationship between chromaticity and edge condition demonstrates is that the distinctness of the outline of a shape affects the perceived saturation of a target color.[1]

The relevance for sunflower at sunset yellow of Evans' demonstration is simple but, maybe, not immediately obvious. Distinct shapes intensify perceived colors. Shapes in the landscape at twilight, as long as the sun is visible above the horizon, are quite distinct due to the way shadows are cast. Flat lighting conditions dominate the landscape for a large portion of the day and after the sun has set. Directional lighting conditions dominate the landscape during twilight as long as the sun is visible. Since the setting sun, casts shadows almost horizontally, the shadows delimit the boundaries of objects and thereby intensify their colors.

These twilight conditions enhance form differently than the way form is enhanced in Evans' demonstration and; therefore, I am assuming that precisely delimiting approximately half of the form in directional lighting is, in practice, as good as bounding the entire form. I think this is a legitimate assumption for two reasons. First, because visual perception is so good at inferring shape from shadow, as in the illustrations Gestalt psychologists are fond of using. Second, because self shading (shadows that an object casts on itself) at twilight are nearly obliterated by secondary sources of illumination. This last point needs further elaboration.

Assume a roughly spherical, red object against a medium gray ground is illuminated by a directional source of light from behind. The light source, depending on its precise spatial relationship to the object, creates a visible highlight somewhere on the upper left hemisphere of the object. The highlight is per-

ceived as the lightest part of the scene. The darkest portion of the scene is at or close to the edge opposite the direction of the illumination. As the illumination grades from the highlight to the shadow, everything beyond the intermediate value is a shadow cast by the object onto the object itself. This self shading combines highlight and shadow under midday conditions to create an impression of a convex surface grading from the light to the dark. Lighting under these conditions diminishes the impression of the saturation of the object color. Twilight illumination conditions are different.

At twilight there are multiple sources of light. The sun provides a primary, directional source of light and the dome of the sky acts as one gigantic source of fill light. Therefore, the self shading that normally obscures the color of objects when a point source dominates the illumination in the scene is almost obliterated by the secondary source of light. The result is that the object is more uniformly illuminated and its color is not nearly as diminished through self shading. Yet, the darkest part of the shadow is still present, bounding a sliver of the object opposite the directional source of illumination, which is still an order of magnitude brighter than the fill.

The self shading, which under (cloudless) midday conditions obscures the color of objects and which also contributes to an accurate reading of objects deep relief, under twilight conditions mostly disappears. Shape recognition becomes less a matter of reading shadow and graded self shading over a surface and more a matter of reading relatively flat color and a slim

but very pronounced shadow. The net result is that object colors appear more saturated because they are more fully illuminated and because the colored objects are (half) clearly defined by a shadow. Under these conditions objects tend to appear flatter, what may be described as "colored silhouettes." In this way twilight lighting conditions conspire to create an intensification of object colors by the reduction of self shading and the definition of edges.

Color+Brightness

The domain of psychophysics is concerned with the relationship between color and brightness. The chromaticity diagram is constructed to render exactly this relationship for the largest group of colors possible. The boundary of the chromaticity diagram is the spectrum locus which is made up of homogeneous colors, colors of a single dominant wavelength at full purity. The center of the chromaticity diagram is a white point. The point is called "white" because all the spectral colors (dominant wavelengths on the perimeter of the horse shoe shape but excluding those on the "purple line") combine to give white (achromatic) light. This white point serves two purposes. It allows purity to be defined as a linear relationship between achromatic light and dominant wavelength and it allows the relative brightness of the plane in which this linear relationship occurs to be defined as the log of luminance (fig.81).

In the Kansas landscape I stopped to observe the sunflowers because they seemed to be as bright as the sun. I knew already

that this could not be the case. The sun was illuminating the sunflower petals and there is no physical reason the color (light reflected) from the sunflowers could be of the same magnitude of luminance as light of the sky, let alone of a blood orange orange sun. In order to test what I already knew to be the case I stopped the car and moved close (slightly below) a sunflower. Juxtaposing the petals of the sunflower and the setting sun I expected the yellow of the sunflower petals to appear less saturated (technically less "pure"). When I did this I observed that the yellow of the petals was 'not so much less saturated as it was lighter without being whiter'.

What variable of the color of the yellow petals changed? The yellow was not less pure because white light was not added. The hue of the yellow did not change because it did not become more red or more green.[2] Therefore the brightness of the petals must have changed but the curious part was that the brightness changed without altering the saturation. Typically when brightness changes colors appear less saturated. When brightness is increased by shifting a target color from the shade into direct sunlight it looks as if achromatic light was added to the target color, decreasing its saturation. If, on the other hand, the target color is moved from bright sunlight into shade it seems darker, which also desaturated the color.

In both cases changing the brightness of the target color changes the saturation, but this is not what happened when I juxtaposed the petal and the sun. The variable that changed in my impression of the yellow petal was, of course, chromaticity

and this experience is what the chromaticity diagram describes.

The axis of luminance (the psychophysical correlate of brightness) runs through the white point at the center of the chromaticity diagram, perpendicular to the plane of the spectrum locus. At different general levels of illumination, considering non-self-luminous colors, the distance from the white point to the spectrum locus changes and the overall shape of the spectrum locus changes. When I juxtaposed petal yellow with the back lit orange sun I shifted the luminance context of the yellow and therefore the yellow still appeared as fully saturated. The target yellow was simply shifted to a different horizontal section of the three dimensional space of the chromaticity diagram. Since the boundary of the spectrum locus (in the frame of reference of the petal color) is slightly smaller on the chapter that the petal yellow was shifted towards, the yellow seems lighter. But, because the ratio of the distance from the white point to the target color to the distance from the white point to the spectrum locus was nearly identical on both sections, my impression that the saturation of the yellow did not change was substantially in agreement with the psychophysical model (fig.82).

I suspect this tendency of the impression of colors to change in brightness but not in saturation is especially pronounced for colors at or near the spectrum locus. For colors located noticeably inside the boundary of measurable chromaticity the shift to a different level of luminance accentuates the differences between their respective purities (due to the Bezold-Brucke effect, see chapter 4). For colors on or near the

spectrum locus, because there is only a very small white component in the color to begin with, the luminance shift also makes the color appear different. It is different in a way that is difficult to describe since one must somehow account for a relationship among relationships. This is precisely the great strength of visual psychophysics since the model factors in variables for the sensitivity of the eye, the color temperature of the illumination, as well as the relationship between hue and brightness. Thus, I am left with a question. Since the relative luminances of the scene does not, in my estimation, entirely account for the flower petals vividness, what does?

Adaptation

The adaptation context of the scene is given in terms of two variables. One is brightness adaptation and the other is chromatic adaptation. The brightness adaptation of the sensing eye at twilight is midway between an adaptation to full daylight, photopic adaptation, and adaptation to night vision, scotopic adaptation. The technical term for this condition is mesopic adaptation and it is a curious condition indeed (fig.68). Given the foundation of psychophysics in a duplicity theory of vision--which states that there are two different sets of sensors (rods and cones) that respond to light under different lighting conditions--scientists assume that one or the other system is engaged but not both. This assumption may or may not turn out to be justified, no one knows yet because the phenomenon of mesopic adaptation is just beginning to be studied,[3]

yet; some of the significance of mesopic adaptation is hinted at in Kirschmann's third law of color contrast: "color contrast is at a maximum when luminance contrast is at a minimum" (Walraven, 1976:289). These are precisely the conditions of the gloaming, where the fill-light from the dome of the sky diminishes the brightness contrast between the highlight, the self shading and the shadows of objects in a scene. Furthermore, I suspect rod vision is partially engaged at the gloaming thereby complicating the sensing of trichromatic information. At the very least, the brightness response of cones is depressed (relative to photopic adaptation) and subjectively, color contrast is at a maximum.

One way to quantify the ways color contrast is at a maximum was presented above through the work of Jameson and Hurvich. Recall that they established a scale, called chromatic valence, that measures the response to dominant wavelength in the context of a specific state of chromatic adaptation. The possible states of adaptation are given by the opponent pairs red-green, yellow-blue and in general, adaptation to one color of a given opponent pair suppresses the response of the system to that color and enhances the response to its opposite, while the magnitude of the response to colors of the other pair remains unchanged.

Jameson and Hurvich, by comparing the curves from different states of adaptation, were also able to show that not only are the magnitudes of response to a particular dominant wavelength different under different circumstances, but that, because the general curves shift relative to the ordinate, different wavelengths constitute different unitary colors (dominant wave-

lengths characteristic of the opponent colors), given different states of chromatic adaptation. Finally, remember also that chromatic adaptation is extremely sensitive to small deviations between actual observers' and the standard observer's basic response curves and that observers may be adapted to more than one unitary color at the same time. The work of Jameson and Hurvich comes close to accounting for the experience of vivid color in a west Kansas landscape. I want to connect several aspects of their findings to what I experienced.

First, concerning the magnitude of the response to white in a state of neutral chromatic adaptation, note that it is located, by definition, as a response of chromatic valence of 1.00. Now compare the magnitude of the response to green, red adapted, which is slightly less than 1.50 (see fig 83). The difference in the magnitude of the responses provides another indication of the way achromatic response may be said to be suppressed at twilight, given a state of red adaptation.

I am assuming here that the blood orange sky, spread wide across my whole visual field provides the conditions which constitute red adaptation. Not only is the horizon deep orange but the wavelengths of light, filtered through the moist air of the far distance, are in the red/orange range, immersing the landscape in a warm orange glow. Under these conditions the chromatic response to the greens (ground cover) is greater than the response to white under conditions of neutral adaptation. This finding does not quite confirm Kirschmann's third law, which compares brightness contrast and color contrast; though,

it is corollary to it.

Secondly, the red adapted state accounts well for the vividness of the green of the ground cover and the proliferation of greens in my field of view, even though I am facing away from the sun. Apple-green, willow-green, swallow-gray, jade, lotus stem, silver green, ink wash, litche, and duck's-head green are all a product of illumination, object composition, and my red adapted receptors. The greens proliferate and are easily differentiated because my red adapted state is carried over from a fixed view of the sun and successively contrasted with greens in the landscape and note, there are no pronounced reds in the landscape. Peach-pink and coral color are both desaturated reds that under different conditions might appear redder, more saturated. Other colors in the landscape; sauce brown, sky-blue, fish-belly-white, ink wash, pebble-blue, are not particularly surprising except for perhaps fish-belly white which I take to be a thick color. In this case a warm, self luminous cream, the product of some light toned hay illuminated by the orange glow of the sun setting behind my back.

The colors of the sky are also not particularly surprising. 'The cloud bank is an absolutely hueless gray with a motley fringe decomposing towards the zenith into a wispy, lilac rose. Sky colors grade from azure, to indigo, to smalt, to cerulean at the horizon opposite.' The bank of clouds are gray because no light from the sun is escaping the clouds on the side from which I am viewing them. The clouds are not black because the albedo (reflected light from the earth or other clouds) of the earth is

lightening them.

Towards the edges of the clouds, from my vantage point, light is scattered at the colored fringe. I have not attempted to name these colors since the subtle blending of color into color makes it impossible to isolate patches of color that might be named. Looking at the fringes of the clouds through a reduction screen would disrupt the very gradation that gives these colors their character. 'Wispy lilac-rose' is a different matter.

This sky color is unusual though not unique. It is a product of thin cirrus clouds, high in the atmosphere, scattering the rays of the sun towards the red, optically fusing with blues from the remainder of the atmosphere. It is a striking because it is the thickest color possible, an aggregate of colors inter-penetrating over thousands of feet, impossible to locate definitively at some specific distance from the viewer.

Approximately forty to fifty degrees above the horizon the band of lilac-rose ends and the remaining colors of the sky are all species of blue. What is interesting about the gradation of blues in the sky is where the darkest blue occurs. It occurs just below the zenith of the dome of the sky at about fifteen degrees to the west of the zenith (fig.84). Therefore the sky grades, in terms of brightness, from a medium to dark to medium to relatively light to very dark, as the shadow of the earth blocks all the light of the sun. It is actually quite fun to watch the onset of night in the direction away from the sun, realizing that what one is seeing is the advancing shadow of the

earth projected onto the sky. Occasionally one witnesses spectacular effects after the sun has set, before the onset of astronomical night. The sky is in the shadow of the earth but tall cumulous clouds are still painted orange by the rays of a sun the viewer can no longer see. But, I digress and have yet to describe why the sunflowers were so yellow.

Actually the reason should be obvious--in hindsight. I was blue adapted as well as red adapted and the blue adaptation spiked my subjective impression of yellow. The effect was pronounced because there were so many bright yellows in the scene. Clearly this was a cultivated field of sunflowers and they went on for acres. Typically there is not that much bright yellow in a landscape and not only was I particularly receptive to yellow, but patches of yellow were (almost) everywhere in my field of view, reinforcing yellow, more yellow, yellow evermore4. What was the source of blue adaptation? The sky, of course, though blue adaptation and its corresponding hyper-sensitivity to yellow is not induced in quite the same way as red adaptation and its corresponding hyper-sensitivity to green is induced.

I maintain that the orange sunset, with an orange orange sun in the middle of it, was the primary cause of the super-saturated greens that appeared in the landscape (which I experienced successively) and that the warm orange (scattered) light of the sunset only secondarily contributed to the vivid greens. I regarded the orange atmosphere for so long and so fixedly that I could observe a great deal of the landscape for quite some time and still experience a heightened perception

of green based just on the subject of my pervious fixation. I maintain that the greens were primarily "successively" heightened and only secondarily "simultaneously" heightened. The super-saturation of the yellows happens the other way around.

I do not think the blue of the sky was bright enough, nor did I stare fixedly at it in such a way that the blue response could have been engaged from a steady fixation. Instead, it was a preponderance of short wavelengths in the scene to which my eyes became adapted. Here, I am following Monet's lead in thinking that the enveloppe of light, especially at the gloaming, is blue, blue-violet.

Luckily, the preponderance of short wavelengths at twilight is born out by scientific measurement. A graph from Barrow (1995) (fig.85) confirms the relative dominance of "blue light" at twilight relative to midday and relative to longer wavelengths in the twilight enveloppe. It is difficult to read this phenomenon since the "blue light" does not paint objects with a noticeable warm glow as does the light of the setting sun, though in retrospect it does seem obvious.

The conditions were ripe, even the direction in which the sunflower heads were facing. In the story they are pointed away from the sun. Why this was so is not clear since it is well know that sunflowers are photopic, responding to the source of light by changing the orientation of their heads. I think the heads were not pointed towards the sun because about late morning they lost a source of light to track due to cloud cover. By the time I arrived their faces were oriented in such a way that they were

illuminated only with the secondary source of light from the dome of the sky. The blue illumination context acted as if the already bright yellow of the petals were viewed against a bright blue-blue violet background, saturating the yellow by simultaneous contrast.

Jameson and Hurvich's model of adaptation based on opponent processing is important because it unifies two effects in one explanation. Successive and simultaneous contrast (what Jameson and Hurvich call temporal and spatial color effects) are reactions of the visual system in the same way to different conditions. It is also theoretically possible in their model for one person to be simultaneously adapted to two different colors. In the Kansas landscape I experienced two different states of adaptation at the same time which heightened my impression of both green and yellow.

Finally, the fourth point of correspondence between Jameson and Hurvich's findings and sunflower at sunset yellow. Out standing in the field, I was left with the impression of a unique yellow that was very different from the yellow characteristic of photopic conditions, neutral adapted. My impression was that sunflower at sunset yellow was the yellowest yellow possible; that it was stronger, simultaneously more gamboge and more ochre, than a typical unitary yellow. In other words, introspective evidence indicates that unitary yellow shifts its hue as well as its saturation under blue adapted conditions--an impression also predicted by Jameson and Hurvich.

In conclusion, I think it is plausible to assert that sun-

flower at sunset yellow is a product of my imagination and that it corresponds to objective conditions present and measurable in the scene. It is true that slight deviations of my response curve relative to the standard observer might account for some of what I experienced as a particularly vivid color, that other (so called) "color normal" observers might not appreciate to the degree to which I did. In the end we may never be able to quantify these minute differences given intrinsic differences in the processing of colored stimuli and sensitive dependence on initial conditions. This is as it should be, for I am the last person who would desire to reduce the magic of color to a set of formulae. On the other hand, I would like to steal a little bit of the vividness of sunflower at sunset yellow for a description in psychophysical terms, if only because that might make possible the framing of other questions, questions that might edge Monet's science and von Helmholtz' art slightly closer together.

Correspondence

The question remains: just what does vivid yellow correspond to in terms of the psychophysical model of color? Let us turn one last time to the CIE (1931)[5] chromaticity diagram. Recall that the chromaticity diagram is an imaginary space, based on a mathematical operation that transforms the spectral sensitivities of an ideal eye into three response curves that correspond to the distribution of spectral energies to which human eyes are sensitive (fig.48). The chromaticity diagram graphs two of these variables (the third is always discoverable

because it is assumed that the intensity of the three variables of spectral response sum to unity) in a plane space. The depth of the three dimensional space is given, in layers, by the log of luminance or by the brightness adaptation of the sensing mechanism. Outside the boundary of the spectrum locus and the purple line lie the imaginary colors, so called because they appear to be of higher chromaticity than any dominant wavelength that may be measured (fig.30).

In this context Billemeyer and Salzman (1980) give a schematic definition of vivid yellow as "unreal[6] red + unreal green = vivid yellow at 570nm" (p.36) (fig.86). According to them and to the conventional wisdom about highly saturated colors, vivid yellow is located on the chromaticity diagram at or slightly inside of the spectrum locus. They are well aware, as was von Helmholtz, that certain contrast effects of juxtaposed (complementary) colors may heighten the subjective impression of yellow. Yet, until the work of Jameson and Hurvich, no one was able to quantify the amount of this intensification and no one has since attempted to use the chromaticity diagram to show the relationship between spectral colors and subjective colors that are the product of related complementary colors.

The reason for this is simple. The chromaticity diagram is a stimulus color space (an attempt to match the spectral distribution of light to the expected color response) and there is no single spectral distribution of light that yields a subjective color produced by color contrast. Does this mean that the chromaticity diagram cannot be used to account for vivid colors?

Perhaps, but I do not think so.

Vivid Color

Assuming that unique yellow is an homogeneous color (a light of purity 1 at 570nm), where is vivid yellow located? "Vivid" has no rigorously defined correlate in the color space of the chromaticity diagram but it is used as a descriptive term in the ICCS-NBS color dictionary. There it is used as the brightest, most saturated manifestation of one color on each of of twenty six "leaves" of colors (see chapter 4). Therefore, in the ICCS-NBS color dictionary, as well as for Billemeyer and Salzman, vivid yellow falls on or just inside the spectrum locus (see fig.87).

I propose, on the other hand, that vivid yellow falls outside the spectrum locus, by definition. If vivid yellow is the product of a contrast effect, the result of juxtaposing homogeneous yellow and homogeneous violet, then it must be located beyond the spectrum locus (see fig.88). Two obvious questions arise: what phenomena would push vivid yellow beyond the spectrum locus and how far would it be pushed?

I have dealt with the phenomena that might push vivid yellow beyond the spectrum locus in this chapter as the layers of sunflower at sunset yellow, namely: frame, displacement, medium, shadow, color+brightness, and adaptation. Of these layers, frame and displacement do not lend themselves to measurement in such a way that they could be included as variables in psychophysical experiments. These layers are

simply too subjective (context dependent) to be of much use in attempting to quantify vivid yellow.

The relationship of shadow and the intensification of color is a different matter. The correlation of boundary conditions and chromaticity appear to be quite strong, as in Evans diagrams illustrating the intensification of perceived saturation in bounded shapes. I have discussed how this effect, including the combination of directional lighting with a reduction of self shading pushes vivid yellow outside the boundary of maximum purity.

The way color is intensified in a medium, where color and shape conspire to to create odd perceptual hybrids--deep planes, thick colors, space comprised of surfaces--also contributes to vivid colors, but only at or near some specific distance characterized as optical fusion. This kind of vivid color is not operational in all situations but it may, under specified conditions, contribute to pushing vivid yellow a little way further beyond the spectrum locus.

The most profound way yellow is rendered vivid is in chromatic adaptation. Under these conditions vivid yellow is pushed some distance beyond the spectrum locus. Here, as above, specific conditions are required for the effect to happen, but happen it does and it seems we have ample visual evidence that color at the gloaming is constituted differently than color at midday.

The relationship color+brightness, of course, defines the spectrum locus so the affect of this relationship does not con-

tribute to the impression of vivid yellow. The way purity is defined in the chromaticity diagram does, however, suggest an approach to the question how far beyond the spectrum locus vivid yellow is located. Since the white point is no longer the source of illumination might purity, in a state of chromatic adaptation, be conceived of as the distance from the color temperature of the adapting illumination to the target color? The difference between this length and the distance of the target color from the white point (purity of 1) might be, at lest conceptually, the distance vivid yellow is located beyond the spectrum locus.

I am not a psychophysicist and therefore I will leave the mathematical formulation of the sunflower at sunset yellow to someone who understands the intricacies of experimental psychology and the mathematics of visual psychophysics and I submit for your consideration that we no longer face von Helmholtz' problems. He lived in a time when an explosion of chemical inventiveness was creating new pigments at a staggering rate. At that time there was great need, yet no means, to establish unambiguous relationships among individual colors. Our problem is different. The measurement and specification of color, by no means exhausted as a subject, is nonetheless well trodden territory. Our problem and our opportunity is to figure out how to put all the pieces of visual processing together in more complex experiments. I maintain that paintings and buildings provide just such a laboratory.

Notes to Chapter Six

1. I did not check for the persistence of the illusion at twilight but I assume it is still operable since it proved to be so robust under a full range of other lighting conditions.

2. Actually there probably was a slight hue shift due to simultaneous contrast but let us ignore this for the moment.

3. The earliest mention of mesopic adaptation with which I am familiar is Kinney (1955). The earliest extended treatment of mesopic adaptation with which I am familiar is in Evans (1974). Representative of the current interest is Howard (1990).

4. Michael Benedikt in a chapter on color from an unpublished manuscript "The Depth of Color," describes deep colors well. Deep color is color that is intensified by myriad reflections among like colored surfaces, similar to what I call "thick" color above. He uses the example of light passing through multiple filters of the same color (technically of the same "absorption" characteristics) to illustrate the intensification of color. Given the spectral distribution of the light source and the reflectance characteristics of colored surfaces that are oriented towards each other in such a way that light reflected off of one surface is reflected several more times off of other similarly colored surfaces, he explains 'color, more color, color evermore' using an elegant model. Assume the initial illumination is an ideal "white" (fig.59). The difference between the spectral distribution of ideal white and the spectral distribution of the singly reflected color is lost to visual perception since it is absorbed by the surface as heat. Assume that this initial reflection creates a spectral signature

with one pronounced hump. When the light is doubly reflected the color appears stronger and dimmer. It is dimmer in a double reflection because the spectral signature of the illumination is reduced by the second reflection. The color appears stronger because the dominant wavelength (the "hump") of the spectral signature is not reduced as much as the portions of the spectral signature that are not dominant. Myriad reflections of light from similarly colored surfaces, therefore, has the effect of quickly filtering out the portions of the spectrum that are not dominant in the object color. In the Kansas landscape the yellow of the sunflowers is intensified by myriad yellow objects which mimics multiple reflections.

5. The CIE has created a number of chromaticity diagrams based on differing requirements in the spacing of colors. The 1931 diagram was the first of these color spaces, and although it is now only one of several ways to visualize psychophysical relationships among colors, it is as valid now as it was when it was formulated.

6. Red and green, in this case, are called "unreal" in reference to the mathematical operation that transforms the spectral sensitivity response to "real" colors into "unreal" numerical fictions. If the variables of the three response curves are r-, g-, and b- and the mathematical transformation of these variables yields x-, y-, and z- (respectively), then the r- curve, which has a negative component, is treated as positive x where it was negative r- and the corresponding response of g- and b- in y- and z- is increased proportionately (fig.48).

VIVIDNESS IN ARCHITECTURE

> *The question is not whether ordinary people can understand sophisticated architecture (they cannot), but whether anyone can "read" these buildings with the buildings... the critical power...lies first in the speaking, writing, and drawing...and then, at best, in the relationship of these texts to the built object. Buildings themselves constitute neither the texts nor a true language; their complex of meanings and their subtle powers operate almost exclusively at pre- or non-linguistic levels."*
>
> Michael Benedikt (1991:7)

Given that the phenomenological analysis of Monet's Grainstacks (End of Summer) is problematic (because we are dealing with visual perception of a visual representation of multiple perceptions) and that "Sunflower at Sunset Yellow" is doubly problematic (because we are dealing with a verbal representation of a visual representation); it might be said that this chapter, dealing with Balthasar Neumann's Benedictine Abbey Church of the Holy Cross (fig.89), is thrice problematic. Here we are dealing with an object of perception that has no referent but itself.

Strictly speaking the same may be said of any painting since, as in Heinrich Wofflin's justly famous dictum 'pictures owe more to other pictures than they do to nature;' but, at least in Monet's case, I assume that we have some basis on which we can speculate about the conditions that guided Monet's hand towards some of the choices he made. Likewise, I assume that we may use Sunflower at Sunset Yellow, even in the verbal description of an otherwise unrecoverable phenomenal experience,

as a narrative that temporarily sets the flux of experience so that it might be compared with other, more stable descriptions.

In this discussion of Neumann's magnificent church, I can not offer even these tenuous threads to consensual realities. Architecture is not a representational art, when architecture is considered in a building itself rather than in the process of making drawings from which buildings are built. Then why apply the insights of perception derived from painting to architecture?

I am following this course because the question of the limits of visual perception in architecture is, for me, a critical issue. In one sense perceiving buildings is like the perception of vivid color because vivid colors are impressions of color where the conditions of observation conspire with the conditions of the observer to create significance; where significance is wholly given neither in the conditions of the observer nor in the the conditions of the observation. In another sense buildings cannot be vivid in the way colors are (discounting Platonic metaphysics) because there is no prior referent conditions of the observer and conditions of the observation evoke. But, these introductory remarks are far too general to of much use. Let us consider a building, Neumann's Benedictine Abbey Church of the Holy Cross (1748; figs.93 through 102)[1].

The Frame

My frame for Neumann's church at Neresheim was as simple as it was broad, "What is Baroque architecture and why would anyone

choose to design or build in such a cloying style?" I explicitly formulated this question before a trip to Central Europe in 1985. During that trip I visited several projects designed by Neumann and many other notable German Baroque churches. I visited the Wurzburg Residenz, and the Wurzburg palace church. I visited Neumann churches at Kitzengen, Graibach, Bruchsal, and Neresheim. I visited anything called "Baroque" listed in the Michlain Guide, including the Neumunster in Wurzburg and Die Wies pilgrimage church, considered by many the apotheosis of German Baroque Architecture. From the beginning Neumann's work stood out from the rest. His massing, the juxtaposition of solid and void, ornament and plane surfaces, appealed to my mid-western (Protestant) sensibilities more than the decorative confusion of, for instance, Die Wies.

The Church of the Holy Cross at Kitzengen-Etwashausen (1751)1 (figs.90-92) is a particular triumph. A modest structure with little ornamentation, it seems its' patrons had a limited budget and less desire for decorative extravagance (fig.90). The barrel vaulting over the nave and apse of the squarish plan (fig.91) perfectly compliments the flattened spherical vault over the transept. Half domes over the arms join the transept dome lower than the highest point of the barrel vault and the resulting complex curves are quite sensuous (fig.92), even more so because the day was overcast and the light inside the church was quite subdued.

Kitzengen is not particularly representative of German Baroque sensibilities and I quickly concluded that Neumann is,

in general, not particularly representative of Baroque architecture. Instead I see his work as situated in a tradition that uses light and the fugitive play of light over surface, to create a shifting impression of vivid materiality.

What is important is that the tradition Neumann is representative of, is not a stylistic tradition. Buildings from many different periods are exemplary, including the Parthenon, Chartres, Borromini's S. Carlo alle Quattro Fontane, Neumann's Church of the Holy Cross at Neresheim, Jefferson's Rotunda and Kahn's Kimball museum It is not a common style that makes these buildings exemplary, but a fascination with interiors and natural light. A viewing of Neresheim provided the evidence on which this conclusion is based, but as I approached the church from the valley below, there was only a question about baroque[2] buildings, proactively bracketing what was seeable, retroactively engaged through what was to be seen.

I have been at great pains in this argument to establish a non-literal definition of frame yet at Neresheim there is a literal frame that plays a role significant enough to mention. The framing of the interior of the church by the entrance under a balcony does not last very long. The balcony is shallow and one quickly emerges into the nave. One is awed, on a tactile/kinesthetic level by the transition from bounded entry to voluminous interior. This technique is, of course, quite common (Frank Lloyd Wright used it to great effect in many of his buildings) but it deserves mention because of the difference in the roles played by frames in buildings and frames in paintings.

In painting frames are a means of differentiating the virtual space of the canvas, board or fresco from the surface on which it rests. Frames, framing paintings are relatively static and if they call attention to themselves rather than to the painting they are a liability. Frames in architecture play a different role.

In architecture frames, because the frame is contiguous with what is framed, hold the view and the viewer in the same space. Visiting a building is not like visiting a picture gallery where the recognition of what is inside one frame may be ignored in the next frame. Architectural frames mark special views and dynamically draw the viewer through a series of significant "moments" in the space, all the while maintaining the connection between frame and framed.

The Medium

Evidence that the medium in which the Church of the Holy Cross is situated is light, was suggested by a visual inspection of the church (figs.96-101). Having inspected the church on the inside, I considered the building from the outside. It quickly became apparent that there are two distinct formal vocabularies. One, on the outside, has square corners and planar walls; relieved by attached columns, decorative capitals, complex built-up moldings, and ornamental roofs, to be sure, is still basically flat and square. The other vocabulary inside was curvaceous, spatially quite deep and supported a succession of ellipsoid and spherical vaults. Of course, the two systems

are related in their structural functions, interior piers stiffening exterior walls which, in turn, allows for large window openings in the outer walls; but, formally they could not be more different.

While I was outside, inspecting that portion of the exterior visitors are allowed to view, musing on the relationships between inner and outer shells, the sun went behind a large cloud. On the exterior of the building the change was quite marked, transforming shadow relief on the facade of the church into an almost uniform, light gray exterior, punctuated by the windows, whose tonality was black (glass reflects very little light so it appears black when viewed from the side of the greatest intensity of light). I headed back into the church to observe the conditions of light on the interior. As I entered I paused under the balcony to allow time to adapt. When I turned around, very much to my surprise, it seemed brighter on the inside than on the outside.

The windows, which are quite large and filled with clear glass, capture enough light, even when the sun is diffused by cloud cover, that the interior is luminous no matter what the daylight conditions. This affect is partially a product of the the interior shell walls which are predominantly white all the way to the top of the entablature; but, I think it is more a product of the "double wall" construction of the building. The space between the inside isle wall and the exterior window wall creates a double (sometimes a triple) reflection of the light entering from the outside the building. This results in an

impression of luminousness on the interior of the church.

The double wall construction also plays the role of "hiding" the windows from view unless one is opposite an opening. Not being able to see the source of the light illuminating the crossing (the portion of the plan where the arms cross the body of the church) from the back of the nave contributes to the impression that the interior is luminous with no external source of luminosity. Of course, one notes the presence of windows, and remembers them; but, the perceptual experience is of a structure embedded in light without a visible source. The very ease with which we locate the source of light (windows) actually contributes to the mystery of diffuse interior illumination, since we half consciously expect the interior light to be more specular (since the windows are so large).[3]

The difference between the visual embedding medium of painting and architecture is that, in this building, the viewer is not required to backtrack down the regress of light contexts at different stages of reproduction in order to reconstruct the light context of the scene. The Church of the Holy Cross at Neresheim simply exists in the context of light. The light context is mediated by a series of reflections that smooth out the differences usually produced by different exterior conditions and, though one may easily verify where the sources of light are, one is not engaged by the work in such a way that the light context must be re-constructed from clues given in a representation. The church is gently luminous and the obvious sources of light contributes to, but does not account for, the

aura of the interior.

Shadow

Given that the medium in which the church is embedded is light, the "shadow" of the object in the medium is its form. The metaphorical definition of shadow adopted in here is somewhat at odds with the literal analysis of shadow offered above. But, if this analysis--which proposes the play of light as the basis for the interpretation of architecture from buildings--is not to make the error opposite of conventional architectural criticism--which all but ignores the light context of buildings--I must offer a structural description of the building.[4]

The Church of the Holy Cross at Neresheim (1748) presents a modified cruciform plan where the length of the nave is equal to the length of the choir. Based on surviving studies (in Otto, 1980, figs. 139-145) Neumann did not arrive immediately at this plan. The Abbot of the monastery made only two programmatic requirements of Neumann; (1) that the Romanesque tower of the earlier church be retained and (2) that two hallways from the monastery, located on the east and west sides of a major court, lead into the church (fig.94). Neumann had some difficulty resolving these requirements using a traditional cruciform plan where the choir is shorter than the nave. The east hallway would have entered the choir at an awkward location or the Romanesque tower would have ended up, functionally, as an element of the facade. His solution to this problem, which was still being elaborated in its details well after the church was under

construction, was an unusual plan where the choir and the nave are of the same length (fig.93).

Another interesting aspect of the plan is the difference in width of the nave and the choir. The reason for this difference is not apparent on a visual inspection of the church and Otto does not justify it except to suggest that the site, which drops off sharply to the northeast, required a lot of fill. The difference in width; however, leads to an unique solution for the vaults over the nave and choir. Two vaults over the nave are elliptical in plan (ellipsoid in three dimensions), oriented latitudinally tangent to one another and to the transept vault. The vaults over the choir are circular in plan and spherical in three dimensions. I was not initially aware of this subtle difference, which allows the length of the nave and choir to be identical but their widths to be different.

The transept of the church (also called the crossing) is covered by an ellipsoid dome, oriented longitudinally, tangent to two more ellipsoid vaults also oriented longitudinally, over the arms of the transept. Where the interior walls of the nave and choir (and the support for the vaults over those spaces) is comprised of piers set at right angles to the longitudinal axis of the church, the vault over the transept is carried on four sets of double columns, detached from the exterior walls. This has the effect of opening up the space of the arms to the space of the transept.[5]

It is interesting to note that the choir end of the crossing dome acts as an effective caesura for the nave of the

church, even though the apse is still a great distance away (fig.97). There is a railing that separates the transept from the choir that is echoed in the torsion arch of the dome above and these two barriers between the alter and the nave--one on the ceiling and one on the floor--serve to delimit the public space of the church from liturgical space beyond, without disturbing the visual continuity of the whole.

The construction of the vaults of the Church of the Holy Cross at Neresheim are atypical of Neumann's standard practice. The reason for this is that died before the church was completed and so the means of construction of the vaults did not follow the standard construction practice at all of his other major church commissions. The vaults at Neresheim were framed in wood, lathed and plastered. Neumann's typical practice was to use wood formwork set on top of the entablature as centering for a single layer of brick, laid in a haphazard manner, doubled one third of the way up the dome, stiffened with irregular ribs (also laid from on top of the vault) covered with mortar and "reinforced" with iron compression rings (fig.103). Otto makes the case that Neumann was a pioneer in developing this construction technique, which was a cheep and easy way to form vaults compared to cut stone which involved the additional expense of cutting and dressing segmental masonry units of irregular angles.

Even the manner of working out the torsion edges of the pendentive arches was quite straightforward (fig.100):

> The torsion arch[[6]] describes a complex, solid geometrical figure which, from both a mathematical and aesthetic point

> of view, is a highly sophisticated statement. As a design on paper and as a built construction, however, this form was simple and direct. On paper, Neumann placed ovals tangent to one another. To construct this project, arches were cut out of the crossing and transept centerings, and the two units joined. When the shell hardened and the centering was removed, the torsion arch resulted as the line of juncture between ovals--the complex consequence of a straightforward approach. (Otto. 1980:44)

Since Neumann did not live to supervise the construction of the vaults they were not constructed in this manner, but we can surmise that he intended them to be so constructed.

Actually there is a very good literal example of the role of shadows in buildings, but I hesitate to mention it because it is so prosaic. I am thinking of the role that built up moldings play in differentiating the parts of buildings and softening transitions. Consider the detached columns of the transept, whose moldings are echoed curve for curve on the interior wall surfaces (fig.98). At floor level base boards root the vertical members at ground level, acting as the visual manifestation of the foundation, which is, of course, invisible. Higher on the plinth the narrow shadow of a fillet introduces a wider shadow to come, the table on which the column base rests (the table in the Church of the Holy Cross is about thirteen feet off the ground plane). The torus base of the column is shadowed on the bottom side but is fully illuminated on the top, which is separated from the shaft by a discreet scotia and another fillet.

It is interesting to note that "scotia" is from a Greek word meaning "darkness" and that all of these moldings, excepting

the table which projects noticeably from the fascia, depend primarily on shadow for their effect. The edge of the table is clearly distinguishable from the plane from which it projects by the edge condition of the molding and it casts a tall shadow that (redundantly) signals the relative depth of this member.

Continuing up the detached pier, the column is not fluted, casting shadows towards its edges thereby changing the orientation of the shading from horizontal to vertical, interrupted by Corinthian capitals. Talking about the "order" of this building seems a little silly since the orders of architecture provide only the most general typology (fig.104). Nonetheless the capitals are specifically Corinthian; reverse bell shaped, complete with acanthus foliage, caulieuli, volutes, and a proper abacus.

The entablature, divided into architrave, frieze and cornice, is particularly dramatic. The architrave, narrower than the width of the abacus, is gently shadowed on a cyma recta. The frieze is un-ornamented and the cornice steps out from the fascia in two dramatic steps, effectively mixing ovolo, cavetto, cyma recta and fillets.

The point I would like to make about molding is the same point I want to make about architectural design in general. Molding designs are almost always pictured as a measured relation between parts in section drawings (figs.105,106). Even though much material has been presented about molding designs, only a few sources discuss the simplest guideline used to design moldings. Moldings should be designed so that they cast legible

shadows, clearly differentiating the parts of the building at different scales. Moldings grade the smallest scale parts into the larger scale elements into the largest scale form and visa versa.

Edward Shaw (1852) discusses molding in this way and illustrates his point (fig.107), but even he provides ten figures of measured relations and geometric constructions of moldings for every one illustration of shaded moldings. I believe Andrea Palladio (1508-1580) considered the shadowing of architectural ornament of overriding importance (fig.108) and, closer to our own time, Louis Sullivan drafted his ornaments as if they were only shadows (fig.109). (Some of Sullivan's concept sketches for whole buildings are similarly conceived, see figure 110.)

In conclusion, if the medium in which buildings are situated is light and the actual shadow of architectural detail differentiates building elements, then discussing the formal/structural disposition of buildings as the shadow of an architectural object in the medium of light turns out not to be so metaphorical.

Displacement

Displacement, the motivation for me to ignore the seeing "I" and attend to the seeing eye, was prompted in the space of the Church of the Holy Cross, by another fugitive effect of light, in this case related to the detached columns of the transept. Form a vantage point at the alter end of the crossing vault the double columns supporting the crossing was backlighted with sunlight streaming through a window at the end

of the transept arm. The light was so bright that it erased the columns.

No particular revelation accompanied this observation and as I paused to consider visually the placement of the windows relative to the detached columns my internal monologue was briefly stilled. Sometimes displacement is the signal of a revelation, but sometimes it is just a little interruption. Sometimes a little interruption is all we need to take one "outside" of one's self. I sat down on one of the pews to catch my breath and shortly thereafter headed outdoors. The beauty of what I was experiencing (and its significance) would emerge, not by an act of will, rather in spite of it.

Color + Brightness

The role of color+brightness in the Church of the Holy Cross at Neresheim is given in the gilded elements. There is no great surprise here since gilding and semiprecious gems have been used for a long time, to great effect, in churches. The use of material splendor in ecclesiastical architecture was the subject of a notable polemic at the beginning of the middle ages in which the Abbot Suger (1081-1151) maintained that all the splendiferous elements that can be used should be used in order to facilitate a person's rising up to meet God. It was in such a setting that Abbot Suger experienced his own ascensio:

> Thus when--out of my delight in the beauty of the house of god--the loveliness of the many-coloured gems has called me away from external cares, and worthy meditation has induced me to reflect, transferring that which is material to that

> which is immaterial, on the diversity of sacred virtues;
> then it seems to me that I see myself dwelling, as it were,
> in some strange region of the universe which neither exists
> entirely in the clime of the earth nor entirely in the
> purity of heaven; and that, by the grace of God, I can be
> transported from this inferior to that higher world in an
> anagogical manner. (Abbot Suger in Panofsky, 1979:79)

Abbot Suger was opposed in the ensuing debate by St. Bernard who took a more Platonic position; that the sensation of material splendor is of this world and that gross materiality has no role to play in a genuinely religious experience.

Abbot Suger, who was supervising the construction of Saint-Denis, was in a position to realize his vision in built form and though this debate has continued in different manifestations throughout the centuries, there is a well established tradition that uses material splendor to promote sacred virtues.[7] Neumann's church with its gilded garlands, candelabra and urns, also exists in this tradition.

There are gilded elements throughout the church; on the entrance screen, on the pulpit (which is located in the nave in front of the transept), on the rail separating the nave from the choir, but, the most pronounced use of the gilding is on the alter and the apse wall of the choir. High on the alter, two gilded urns are placed which, because of their location relative to the apse windows, are particularly splendid. Light from the windows illuminates the back side of the urns and from the choir side of alter, they are irradiant.

A crucifix on the apse wall appears in a gold frame that terminates just under the entablature, at the height of the

capitals. The gilding here, because it is not directly illuminated by light from the apse windows, is of a darker tonality than the urns, but still very bright. Finally, a gilt diaper is used on a yellow orange ground on the edges of the torsion arches. Here the gilding, viewed from a distance in the same visual frame as the alter and the apse wall, is darker still.

Considering again, briefly, the attributes of sensation (fig.40) gold (as the effect of gilding rather than the pigment color) is not locatable in the color space of the chromaticity diagram because it is the product of an "surface" mode of appearance, yet, psychophysics rarely deals with object modes of appearance where the luster of a surface is uncontrolled. This bracketing off of the sensation of gold (and other highly specular reflective materials) from the central concerns of color vision is troublesome. Clearly gold is a color and although it is equally clearly different in quality from scarlet, I think we cannot pretend to have a color theory or a comprehensive color space, until the effects of metallic colors, including their specular reflections, can be accounted for by the general color model.

Adaptation

What is the the adaptation context of the Church of the Holy Cross? Though I have already discussed brightness adaptation with regard to the diffuse interior illumination, I think the general adaptation context is given by the function of the building.

This is a place of religious observance and adaptation best addresses this important part of the experience of the building. Though I am not a religious person, upon entering the church, I am immediately aware that this is a holy place.

Recall from Chapter five the discussion of Michael Kubovy's thesis that Leonardo's Last Supper, promotes a 'spiritual experience' by elevating the cyclopean eye and providing evidence (in the relationship between the real space of the refractory and the virtual space of the painting) contradictory to the newly assumed vantage. The push and pull in this process, when resolved by the viewer, facilitates an impression that the whole is greater than the sum of the parts that can, and often is, interpreted as a spiritual experience.

Even though Kubovy's thesis could be read as a perceptual justification for what cannot be justified (if holiness is justifiable faith stops being faith) and it assumes (1) that sensation plays a role in the experience of holiness and (2) that sacredness does not inure in the object of sensation but in the relationship of object and subject. I agree with these assumptions, convinced as I am that 'abstractions (both religious and scientific) draw their ultimate power from sensuous sources'--even though sensations are not the whole of either science or holiness; but the question is: what sensual experience facilitate the lingering impression of holiness?

The answer is not, of course, singular and some of them I have already discussed above. The light context of the building pushes and pulls, subtly confounding our expectations, resolving

itself as a whiff of the sacred. The relation color+brightness also facilitates an experience of sacredness. The golden ornament, point sources of brightness in the visual array brighter than what human observers can integrate into the scene, promotes an anagogic interpretation. Even the frame of the trip to Neresheim contributed to the impression of holiness. Having visited so many of Neumann's churches and because Neresheim was "out of the way," locating and visiting the church had about it the air of a pilgrimage. I was prepared for "a religious experience" and though there was ample visual evidence of the holiness of this place I do not think the impression of sacredness was delivered visually. The Church of the Holy Cross at Neresheim sounded holy.

What is the sound of holiness? I grew up singing in cathedral choirs so the sound of the sacred is, for me, literally a matter of acoustic feedback. This is the realm in which communal ritual observance and the personal experience of something greater intersects. Early on and for strictly practical reasons I developed the habit of testing the acoustic quality of structures by vocalizing at different points. Unfortunately, at Neresheim I was unable to hear a service which would have provided better concrete observations than walking around humming, singing and whistling, but I did take the acoustic measure of Neresheim and what I herd was a body dwarfed in a live enclosure, nonetheless clearly situated in a particular spatial location.

I think that if there is one sensory channel that is

particularly tuned to the perception of space, that channel is hearing. At Neresheim the size of the volume was my first memorable interior visual impression of the church and that impression diminishes over time. shrinks to a mere trace as one visually regards the details. Yet, as I regard the details, I am never uncertain as to just where I am in the space. The great ellipsoid vaults seem to act as a whisper chamber, reflecting the sounds of movement and vocalization back to me, in certain "sweet spots" noticeably amplified. At other spots the sound arrives out of synchronization, an echo. In still other places sounds arrive in multiples, a reverberation. All of these auditory observations yield information about the size of the interior volume, but it is not the size of the space that sounds holy, it is the relationship between the volume and my particular location within it.

This is a "holy" experience because; though one is only metaphorically located in the immensity of the cosmos (by virtue of being in a church), one is clearly located in the relatively smaller (but immense none the less) space of the building. By being clearly located in the space of the church one is, by extension, grounded (or, at lease groundable) in the space of the cosmos. I do not want to carry this too far. The simple point is that architecture is an immersive reality where information is given on multiple channels. Committed to theorizing about architecture, one cannot, in principle, ignore any of the channels or assume the perpetual dominance of any of the modes of perception. To do so cuts architecture as a means of ex-

pression off from its very source of strength; for the shape of architecture is acoustic as well as visual, olfactory as well as tactile, categorical and phenomenological.

Correspondence

Raising the question of the role of visual perception in architecture and the corollary issue "To what does the perception of color in architecture correspond?" is to open a Pandora's I cannot possibly hope to close here, at the end of this thesis. Therefore allow me to offer some preliminary thoughts with the stipulation that these are to remain open questions.

I assume that architecture is a virtual reality and adopt Susan K. Langer's definition of "virtual entities."

> Anything that exists only for perception, and plays no ordinary, passive part in nature as common objects do, is a virtual entity. It is not unreal; where it confronts you, you really perceive it, you don't dream or imagine that you do. The image in a mirror is a virtual image. A rainbow is a virtual object. (1957:5)

Obviously this definition implies a distinction between architecture and building and though later I will undermine this distinction, for the time being let us agree that buildings are not architecture and that architecture is not wholly given in building.

Recalling the discussion of immersive perceptions from Chapter five, an immersive virtual reality presents a broad bandwidth of information. The size of the communication bandwidth is important because "The effect of narrowing band-

width is to engage more of the participants' interpretive faculties." (Stone, 1995:93)

According to this schema architecture is a broad bandwidth virtual reality, since it is constituted in visual, acoustic, olfactory and tactile modalities; and painting is a relatively narrow bandwidth technology since it is constituted only in a visual modality. Architecture, by engaging a larger bandwidth, is more phenomenological, closer to the experience of perceptual effects, than is painting. Painting is more interpretative, engaging "higher" brain processes to round out information given through a narrower bandwidth. In this sense painting is more abstract than architecture, because the perception of a painting is further removed from the level of primitive sensory processing than the perception of a building.

In another sense though, architecture is more abstract than painting. In this sense abstraction is defined as the distance from the experience of the object to the subjects' experience of the objects' significance, the categorical interpretation of the artifact. Since a building is closer to its phenomenal experience, the distance to its interpretation--the story we spontaneously make up about buildings as objects--is further than the conceptual distance we travel to the interpretation of a painting.

Given that architecture is both more phenomenological and more abstract than painting, is it legitimate to use concepts derived from dominantly visual perception of a painting in an interpretation of a building? I think it is. Painting and

architecture have traditionally been considered sister arts and as far back as Vitruvius painting has been used to substantiate and clarify critical concepts central to architecture.[8] But, this does not mean that critical concepts drawn from a consideration of painting should determine the extent of the critical vocabulary of architecture or that the prejudices of a dominantly visual virtual reality should be accepted without modification in a broad bandwidth virtual reality.

I have argued at length that one prejudice of visual psychophysics is the tendency to interpret form as a primary variable of visual perception and color as a secondary element. As a counter example I have used color at twilight to show how, under certain conditions, the visual interpretation of a scene might be dominantly colored and resolved into form and space as a secondary operation. I think this observation has important

ramifications for the theory of color, but I think it is of even more critical importance in the theory of architecture.

Assuming that the prejudice in favor of form vision in psychology is associated with a similar prejudice in painting, using the effects of painting as the foundation on which the affects of architecture is based, skews the interpretation and even the perception of buildings. It skews the visual interpretation of buildings towards an obsession with form, structure and the measured relations of elements, away from the light context of architecture and it all but ignores the all-sensory interpretation of buildings, including the subtle information available

through the interactions among sense modalities.

Although this thesis does not offer an analysis of the role of psychoacoustics in architecture and assuming that it is as complex as the role of visual psychophysics, I conclude that it is thoroughly legitimate to adopt what may be discovered from perceiving paintings in architecture, with one important caveat. We must bear in mind that the visual cannel is only one of several channels through which we may receive information and that what is borrowed from painting may need to be revised in the context of all-sensory perceptual interactions.

The perception of space in architecture is a case in point. Assuming space in architecture is given in acoustic, tactile and visual channels and presuming that viewers perceive the space of buildings primarily visually. Architectural theory ignores the tendency of acoustic representations of interior volumes to hold the frame and the framed in the same bounded space.

In the end the role of vision in the perception of buildings is of critical importance, but architecture is not only (or even primarily) a visual art. Vision may be the most analytical of all of our senses and tends to give very precise information about differences, (flat not raked, bright not shaded, foreground not background); but I think we depend on the vocabularies of vision for too much of the vocabulary of architecture.

Concerning the asymmetry in painting and architecture of role of representation, I assume that one of the reasons painting is illusionistic, devoted to re-presenting elements

of consensual reality, is that this is one means by which we may make the process of fabricating true fictions more challenging. The challenge to painters (and viewers) is the same whether the illusion is based on unitary perspective construction in a Western painterly tradition or on the multiple perspective construction in an Eastern painterly tradition and making the game more challenging by representing artifacts does not make for the best architecture. It does not work because buildings are not fictions.

Buildings are real objects that exist in the real world that are potentially physically dangerous at the most fundamental level of existence and are equally potentially delightful, also a fundamental level of human existence. What challenges architects is not illusionistic representation but the difficulty of actually making buildings. This is why I would undermine the absolute distinction buildings and architecture. Architecture is greater than any one building therefore the domain of building and the domain of architecture do not perfectly coincide, but I maintain that architecture is not architecture until drawings are realized in built form.

The difficulty with "paper" architecture is analogous to the problem of the reproduction or color in four color printing. In printing, no matter how excellent the master printer, colors can only be approximations. Similarly in paper architecture, no matter how decisive an architectural solution is represented in drawings, the proof is in the pudding not in the rendering. In this sense buildings are experiments that test a whole slew of

hypotheses, in which myriad variables cannot be properly evaluated (or even determined) except in the finished, built product. This is particularly true if one accepts the notion that the medium in which buildings are embedded is light. The dynamic conditions of light interact with the relatively static conditions of buildings to create perceptual objects that are fluid in a way that is closer to perceptual objects in a landscape than it is to the perceptual objects called paintings.

In painting fluidity is given primarily by the metaphorical frame viewers bring to the work. This same frame exists in architecture but it is simplified by a variety of dynamic frames. Each conditional frame, functional, aesthetic, structural, economic, affects decisions in every other frame. In short making architecture a species of painting by pretending drawings of buildings exist as architecture is to misappropriate visual conventions for all-sensory requirements.

Does this mean that architecture as building is better, more interesting, more important than painting? I do not think so. The visual conventions of lighting in painting inform architecture and the case should be made that the visual conventions of space in architecture inform painting. The trick is to figure out how and what is appropriate in the different media.

COLOR in black and white

It is the central position of "Color in Black and White" that no reproduction that can capture the subtle and fugitive affects of color. Neither painting, nor psychophysics, nor

physiology, nor physics can represent, or even comprehensively describe, the qualities of color that are readily apparent to anyone (who is not literally blind) who attends to color in the visual landscape. Therefore, since all transcriptions of colors are proscribed by the technology of the reproduction, I have followed a plan that reconstructs some of these technologies in an attempt to describe what may have fallen between the cracks as color (the subject) fragments into a number of specialized disciplines.

What I believe falls between the cracks is best described as the experience of vivid color, the color of color. The color of color is an affect of visual perception where the conditions of observation and the conditions of the observer conspire to create colors more saturated than can be reproduced or modeled. In this circumstance the conditions of observation may be measured with a great deal of confidence, but the conditions of the observer are more difficult to isolate.

It is my contention that the huge body of warranted assumptions that we bring to the quantification of what can be measured has, over time, yielded so much predictive possibility and so many technological advances that we can no longer see the colors of the trees for the forest of color theory. In challenging this peculiar form of myopia I have examined two well entrenched assumptions in "The abstraction of sight" and "The fallacy of primacy," remote from the cutting edge of current color theory, in an attempt to show how prejudices built into assumptions skew how we understand what we think we understand about

color perception.

"The abstraction of sight" is intended as a plea for a "participatory" epistemology and offers an account of vividness that shows what happens when the observed and the observer are unified in a perceptual field. I argue that Aristotle's position that "thought thinks itself through participation" is not seriously challenged in theories of vision[9] until von Helmholtz and that, though Aristotle's "mediumistic" theory of vision was discarded early on, the essential connectedness of object and subject in visual perception was intact through Newton.

I think a fundamental assumption of participation in seeing is critical to any theory of color. I would even go as far as to temper a rigidly intromission theory of vision with elements of an extromission theory. Even though the literal illumination of bodies in space does not emanate from our eyes, consciously directed attention is at least half of seeing and consequently half of visual perception is attention. Attention might just as well be conceived as an illumination of objects from within the sensorium.[10]

Once the observer and the observed are in principle unified in the perceptual field, it turns out that vivid perceptual responses to beautiful landscapes and automatic perceptual responses to danger in the landscape are very similar. Both heightened awareness's tend to diminish the perceived distance between the object and the subject by taking the perceiving "I" out of the loop of visual processing. The implications for psychophysics is that there is a realm where the unmeasurable

"psychological" variables of the perceiving "I" are bypassed. This suggests that we might be able to devise experiments that test relatively objective responses to very complex (because highly integrated) visual arrays without associative mechanisms of categorical awareness mucking up the trials. Just what an experiment of this type might look like I have not outlined; I have only tried to show that the experience of super saturation, since it is not caused by an objective condition of light, could only be approached through an experiment that presents integrated stimuli--colors integrated with other colors and colors integrated with shapes--in space. In other words a presumption of the difference between sensation and perception, at this point, unacceptably restricts what we can discover about seeing.

"The fallacy of primacy" is an attempt to show that the most basic requirement of our participation with colored objects must circumvent the decisive intervention of a categorical response in seeing. This chapter is not intended to deny the importance of our individual and collective conceptual apparatuses or even to pretend that there is such a thing as an innocent eye. I simply try to show that the concept "primary color" subverts the process of looking by substituting words for visual experiences, suggesting that a kind of suspension of disbelief (the suspension of apperception) is possible and desirable.

This chapter ends with an exposition of the terminology of visual science and, as such may seem like a little schizophrenic

in the context of a criticism of color language. Yet, the conceptual categories of visual science, though based on the rejected premises of primary colors and the separation of sensation and perception, are very effective tools for describing the affects of color, tools no serious attempt to account for the phenomenon can do without.

Once the conceptual apparatus is in place I turn to the consideration of two colored objects, Monet's Grainstacks and sunflower at sunset yellow. The result of a close consideration of Monet's painting is the obvious conclusion that the perception of space and the perception of color are closely bound up with one another. The tentative conclusion of this chapter is that though primitive visual processing of a dense sensory array may transpire from the bottom up, less primitive processing (processing that is not yet a "higher" brain function) may take off on one of three tracks. The tracks are dominantly (1) formal / spatial, (2) colored, or (3) linguistic. Each of these tracks provide critical information about attributes of the world and though we may switch with remarkable facility among the tracks, there are only weak connections between the functioning of the distinct perceptual mechanisms. I identify these perceptual mechanisms with the layers of the interpretation of Monet's painting, designing a schema that allows me to test the perception of a colored object and the perception of spatial object, both from vivid contexts.

This schema applied to "Sunflower at Sunset yellow" tries to show that when dealing with complex visual phenomena the sum

of the parts is greater than the whole. Each layer of the experience of vivid yellow pushes the intensity of the yellow a little further beyond the theoretical boundary of colors for which we can account. The aggregate affect of the layers, under conditions which favor dominantly colored perception, seems to result in a trade off between spatial acuity and color acuity. The tendency of human observers to resolve visual scenes into internal representations in which the object and the subject are embedded in the same three dimensional coordinate frame is aborted and we are content to allow the scene to remain in a 2-1/2 dimensional, vividly colored, frame.

The same schema, applied to Neumann's Church of the Holy Cross, an object of great spatial complexity and relatively less color, attempts to show something altogether different. Neumann's church, as an object of perception, indicates the way a dominantly spatial processing track may switch modalities, seeking information about the object in different senses tuned to the interpretation of different subjective correlates of objective conditions. Where the perception of vivid yellow is constrained by the dominant visual presentation of stimuli the perception of a building is not so constrained. Some buildings, in the particular, and some of what is considered great architecture, in general, integrates sensory information across different sensory channels. I think this is exactly what architecture, as a perceptual technology, is intended to accomplish and I think the critical vocabulary of architectural criticism is far too dominated by the assumption of visual

perceptual conceits.

In conclusion, I have attempted to elucidate as many different methods for mapping color into our perceptual representation of it as possible in the hope that the integration of radically different technologies of representation might create a whole greater than the sum of the parts. But, the curious result of analysis is that after the component parts are displaced it is difficult to re-assemble the whole. In other words I have discovered just how difficult it is to put humpty-dumpty back together again. There is no quick fix for this dilemma, I can only make an appeal. Change your frame of reference. Go back and re-read the story that opens this thesis. Read it in the spirit of our native ability to hold two logically contradictory thoughts as if they are both true; because for us, the 'rays are colored' and the best way to study them as such, is in black and white.

Notes to Section Seven

1. I have adopted the date of the setting of the corner stone as the date of the building for both Kitzengen and Neresheim, realizing that at Neresheim construction on the interior was not completed for another thirty years, well after Neumann's death.

2. I shall adopt Jorge Luis Borges definition of the baroque:

> I should define as baroque that style which deliberately exhausts (or tries to exhaust) all its possibilities and which borders on its own parody..."Baroque" is the name of one of the forms of the syllogism; the eighteenth century applied it to certain excesses in the architecture and painting of the century before. I would say that the final stage of all styles is baroque when that style only too obviously exhibits or overdoes its own tricks. The baroque is intellectual, and as Bernard Shaw has stated all intellectual labor is essentially humorous. (1974:11)

In some ways this definition is too simplistic, especially for the stylistic context of Neumann's church, but I like the "humor" part. Neumann's Baroque seems not to take itself too seriously while acknowledging the critical importance of the enterprise.

3. A contemporary project that utilizes a similar triple reflection to great effect, in this case combined with color, is Steven Holl's design for the D.E.Shaw and Company offices in New York City (in Riley 1995:68). Holl, however, does not allow the exterior windows to be visible from within the lobby space, where he uses the double wall construction. For this reason, though the effect is spectacular in the photographs, it may be diminished because the viewer can not resolve the question "where is the light coming from?" based on personal inspection. This observation is made "out of school," so to speak, for I have not viewed the space in the flesh, only in photographs and

the additional role of color may render it moot.
4. This discussion follows the analysis presented in Christian F. Otto's Space Into Light: The Churches of Balthasar Neumann (1980).

5. Even though windows set in the exterior wall of the arms are not hidden from view in the same way as they are in the nave--by the interior shell of the church--unless one is under the crossing vault, the windows still provide illumination for the interior without being visible from the nave.

6. Otto's term "torsion arch" is not in general use. Other terms used to describe these arches are: three dimensional arch, diadem arch, convex arch, spherical-curved arch. (See Otto, 1980:156 n.4)

7. What I particularly appreciate about Saint-Denis is that while Abbot Suger provided eye candy for the vulgar many he also provided mind candy for the learned few. St. Denis, which is now mostly stripped of its precious and semiprecious gems, was also studded with writing on the walls in the form of incised Latin inscriptions. Abbot Suger seemed to understand that learned need their spiritual crutches as much as the common folk and catered to both their needs in the cathedral, as built.

8. A notable example is Colin Rowe and Robert Slutzky's often cited "Transparency: Literal and Phenomenal" (1976). Rowe and Slutzky develop the concept of transparency using examples drawn from painting and then apply the concept to the work of Le Corbusier and Walter Gropius. Their conclusion, that the essay "is intended to serve as a characterization of species [of transparency] and, also, as a warning against the confusion of species" (1985:176) is unconvincing. I read the essay as an appreciation of the "phenomenal" spatial complexity of Corbusier's League of Nations proposal as opposed to the less

interesting "literal" transparency of Gropius's design for the Bauhaus at Dessau.

9. Theories of vision here are considered as distinct from philosophy, where it may be said that Descartes vanquished a participatory metaphysics.

10. This idea is very close to Aristotle's theory of vision, if one ignores the "inaccuracy" of his physics.

Sources for Illustrations

Citations for the illustrations are noted in the body of the bibliography except where I have used the book cited only for an illustration, in which case they are noted in "Sources for Illustrations" at the end of the bibliography. The number after the date is the page number of the figure in the original source, unless otherwise noted.

Frontispiece. Gemco road sign catalogue

Figure

1. Commenius, 1672:Chapter 62
2. Panofsky, 1954:Frontispiece
3. right: Gombrich, 1979; left: Yarbus, 1967
5. (top) redrawn from Vesalius in Polyak, 1941:fig.21;
   (bottom) redrawn from Walls, 1942
6. Newton, 1952:Frontispiece
7. redrawn from van Heel, 1968
8. Newton, 1952:after page cxvi
9. Crombie, 1958
10. from a 19th C. drawing
11. Crombie, 1958
12. redrawn from Zwimpfer, 1988:fig.1
13. after Nickerson, 1943
14. (left) Jacobson, 1948; (right) by the author
15. Judd, 1966
16. Cleland, 1921
17. Cleland, 1921
18. Agoston, 1979:fig.8.14
19. Cleland, 1921
20. From an informational brochure on color printers.
21. Agoston, 1979:figs.8.1,8.2
22. by the author from text sources
23. Lehner, 1964
24. Lehner, 1964

25. by the author from text sources
26. (top) Newton, 1952:155; (bottom) Descartes from Gage, 1993:fig.185
27. Newton, 1952:127
29. Herrnstein, 1966
30. redrawn from Agoston, 1979:fig.6.9
31. by the author from text sources
32. by the author after Briton, 1914
34. by the author from text sources
35. by the author from text sources
36. by the author from text sources
37. by the author from text sources
38. by the author from text sources
39. by the author from text sources
40. by the author from Committee on Colorimetry, 1943
41. Kuehni, 1983
42. by the author after Billmeyer and Salzman, 1980
43. from Wright, 1969:figs.28,29
44. by the author from Committee on Colorimetry, 1943
45. Sylvania informational publicity
46. Rood, 1916
47. Kuehni, 1983
48. Billmeyer and Salzman, 1980]
49. by the author
50. after Kuehni, 1983
51. Tucker, 1989:plate 1
52. Tucker, 1989:plate 20
53. Seitz, 1960:31
54. Tucker, 1989:fig.42
55. Seitz, 1960:32
56. Riley, 1995:fig.7
57. Gage, 1993:figs.124-7
59. by the author
60. Newton, 1952:6
61. Evans,1974:115
62. by the author
63. by the author
64. by the author
65. Polyak, 1941:fig.43
66. Marr, 1982:fig.2-20

108. Lewis, 1981
109. Sullivan, 1990
110. Sullivan, 1990

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Short Biography
Jack (John Martz) Rees

I came to graduate school late, with a purpose. Late means after running a design and construction business for ten years. My purpose was to write a book. I am leaving school for more practice building.